FINAL REPORT

Liko Nā Pilina: Developing Novel Ecosystems that Enhance Carbon Storage, Native Biodiversity, and Human Mobility in Lowland Hawaiian Forests

SERDP Project RC-2117

AUGUST 2016

Dr. Rebecca Ostertag
University of Hawai‘i at Hilo

Dr. Susan Cordell
Institute of Pacific Islands Forestry, USDA Forest Service

Dr. Peter Vitousek
Stanford University

SERDP
DOD ▪ EPA ▪ DOE

Page Intentionally Left Blank

Page Intentionally Left Blank

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
08/08/2016

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
April 6, 2011 to October 6, 2016

4. TITLE AND SUBTITLE
Liko Nā Pilina: Developing Novel Ecosystems that Enhance Carbon Storage, Native Biodiversity, and Human Mobility in Lowland Hawaiian Forests

5a. CONTRACT NUMBER
11-C-0045

5b. GRANT NUMBER
RC-2117

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER
1.1-1.5, 2.1-2.3, 3.1-3.5, 4.1-4.2, 5.1-5.3, 6.1

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Ostertag, Rebecca

Cordell, Susan (Institute of Pacific Islands Forestry, USDA Forest Service)

Vitousek, Peter M. (Stanford University)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Hawaii at Hilo, 200 W. Kawili Street, Hilo, HI 96720 (Ostertag)

8. PERFORMING ORGANIZATION REPORT NUMBER
DUNS # 195738039

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Public

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This study, used a hybrid ecosystem approach to test whether hybrid ecosystems can: 1) maintain themselves with relatively little input; 2) are capable of sequestering substantial amounts of carbon; 3) sustain a broad range of native biological diversity; and 4) remain open enough at ground level to allow human movement through them. Our objectives were tested in lowland wet forest at the Keaukaha Military Reservation on the Island of Hawaii. A functional trait based restoration approach was used to select the native and non-native species for the hybrid communities planted. The early results of this experiment show that: the treatments have a drastically different environment than the invaded reference con

15. SUBJECT TERMS
Carbon turnover rates, community assembly, complementary, ecosystem services, functional traits, hybrid ecosystem, invasion resistance, redundant

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Rebecca Ostertag
					19b. TELEPHONE NUMBER *(Include area code)*
UU	UU	UU	UU	87	808-932-7573

Page Intentionally Left Blank

Table of Contents

Abstract: 7
1. Objectives 9
2. Background 11
3. Materials and Methods 13
  3.1 Functional Trait Profiles of Lowland Wet Forest Species in East Hawaiʻi 13
  3.2 Using Functional Trait Data to Design the Experiment 17
  3.3 Study Site 19
  3.4 Plot Selection 20
  3.5 Pre-treatment Measurements 21
  3.6 Creation of Experimental Plots 22
  3.7 Treatment Monitoring 24
    3.7.1 Light Availability 24
    3.7.2 Litterfall 25
    3.7.3 Nutrient Availability 25
    3.7.4 Species-level Responses 25
    3.7.5 Seed Rain 26
    3.7.6 Native Recruitment 26
    3.7.7 Decomposition Experiment 26
    3.7.8 Person-hours Statistics 27
  3.8 Development of a Generalizable Model 27
  3.9 Quantifying Ecosystem Services 28
4. Results and Discussion 31
  4.1 Functional Trait Profiles of Lowland Wet Forest Species in East Hawaiʻi 31
  4.2 Pre-treatment Measurements 35
  4.3 Light Availability 37
    4.3.1 LAI and Canopy Openness 37
    4.3.2 Light Quality 39
  4.4 Litterfall 40
  4.5 Nutrient Availability 40
  4.6 Species-level Responses 42
    4.6.1 Survivorship and Relative Growth Rates 42
    4.6.2 Reproductive Phenology 44
  4.7 Seed Rain 44
  4.8 Native Recruitment 45
    4.8.1 Native Seedling Recruitment 45
    4.8.2 Native Sapling Recruitment 46
  4.9 Decomposition Experiment 47
  4.10 Person-hours Statistics 48
  4.11 Development of a Generalizable Model 50
  4.12 Quantifying Ecosystem Services 51
    4.12.1 Forest Biomass 51
    4.12.2 Extractable and Stored Carbon 52
    4.12.3 Biodiversity 54
    4.12.4 Labor and Project Materials 56

4.12.5 Return on Investment…………………………………………………………..57
4.13 Outreach Activities……………………………………………………………….58
4.13.1 Visitation……………………………………………………………………....58
4.13.2 Training Opportunities……………………………………………………….58
4.13.3 Publicity……………………………………………………………………...58
5. Conclusions and Implications for Future Research/Implementation....... **Error! Bookmark not defined.**
5.1 General Conclusions 59
5.2 Implication for Future Research.. 60
5.3 Implementation.. 60
6. Literature Cited 62
7. Appendices... 68

List of Tables

Table 1. Task structure for RC-2117, the Liko Nā Pilina project.
Table 2. List of sites where plant traits were collected.
Table 3. Master list of species with species abbreviation codes used in text.
Table 4. The regular measurements presently undertaken in the Liko Nā Pilina Experiment.
Table 5. List of native and exotic species and their trait values.
Table 6. Characteristics of the plots before any clearing occurred of the four experimental treatments.
Table 7. Aboveground biomass composition of the 'Slow Complementary' treatment
Table 8. Biomass composition in the unmanaged invaded reference plots
Table 9. Potential monetary values of extractable biomass for the 'Slow Complementary'
Table 10. Potential extractable biomass values for the unmanaged invaded reference plots
Table 11. Potential economic benefits from extracting or storing carbon in the 'Slow Complementary'
Table 12. Potential stored carbon monetary values and carbon values weighted per hectare using the proposed 'BioValue' method for the 'Slow Complementary' treatment.
Table 13. Potential stored carbon monetary values and carbon values weighted using the proposed 'BioValue' method for unmanaged invaded reference plots.
Table 14. Projected investment investments in dollars per hectare for the 'Slow Complementary' treatment.
Table 15. Time in years for return on investment in the 'Slow Complementary' treatment

List of Figures

Figure 1. Conceptual workflow of Project RC-2117, the Liko Nā Pilina project.
Figure 2. Location of sampling sites for functional trait analysis.
Figure 3. Overview of the ordination process used to select species.
Figure 4. The four experimental treatments of the Liko Nā Pilina experiment in east Hawaiʻi.
Figure 5. Map of study site and experimental setup.
Figure 6. Map of the KMR forested lands, in relation to the dismounted training lanes
Figure 7. Planting design for the four experimental treatments
Figure 8. Principal components analysis of native and exotic species used to justify the mixing of native and exotic species in restoration treatments
Figure 9. PCA for all species

Figure 10. PCA for all samples of *Metrosideros polymorpha* and *Pandanus tectorius*
Figure 11. Basal area and stem density of the plots before the clearing and planting treatments were applied
Figure 12. Mortality of the dominant canopy tree *Metrosideros polymorpha* between treatments across three census years (2014-2016)
Figure 13. Leaf area index across the treatments for census dates starting with a pre- invasive removal time point in July 2012.
Figure 14. Canopy openness across the treatments for census dates starting with a pre- invasive removal time point in July 2012.
Figure 15. Microsites for the reference and experimental treatments characterized by low, medium, and high light qualities in 2015 and 2016.
Figure 16. Litterfall for the Reference and experimental treatment plots in 2014 and 2015.
Figure 17. Nutrient availability, sampled as nitrate, ammonium, and phosphate for the Reference and experimental treatment plots sampled in 2014.
Figure 18. Nutrient availability sampled as nitrate, ammonium, and phosphate, across the outplant and dominant canopy species sampled in 2014.
Figure 19. Outplant survival across the treatments for census dates since the experimental start in January 2014.
Figure 20. May 2016 outplant survival across the species, in the four experimental treatments.
Figure 21. Outplant relative growth rates across the treatments for census dates since the experimental start in January 2014.
Figure 22. May 2016 relative growth rates across the species, in the four experimental treatments.
Figure 23. Flowering outplant individuals and fruiting outplant individuals recorded monthly from October 2014-July 2016
Figure 24. Native seed mass and invasive seed mass in 2014 and 2015.
Figure 25. Native seedling recruitment for the Reference and experimental treatments.
Figure 26. Native seedling recruitment across the five treatments found in microsites with low, medium, and high light qualities in 2015 and 2016
Figure 27. Native sapling recruitment for the Reference and experimental treatments.
Figure 28. Decomposition rate across the 20 outplant and two dominant canopy species
Figure 29. Decomposition rate across the four experimental treatments
Figure 30. The proportion of effort, in terms of person-hours per project activity starting in January 2012 through July 2016.
Figure 31. Person-hours per month weeding
Figure 32. Degree of invasion across the four treatments.
Figure 33. Screenshot from REST species selection program.
Figure 34. Screenshots showing the PCA output from the REST program
Figure 35. Potential stored carbon high monetary values and carbon values weighted using the proposed 'BioValue' method
Figure 36. Potential stored carbon low monetary values and carbon values weighted using the proposed 'BioValue' method

List of Acronyms

A_{max}	Maximal assimilation
BA	Basal area

BSG	Branch specific gravity
C	Carbon
CTHAR	College of Tropical Agriculture and Human Resources
DBH	Diameter at breast height
DI	Degree of invasion
DoD	Department of Defense
E	Endemic
FD	Functional dispersion
GUI	Graphical user interface
HCl	Hydrochloric acid
HLWF	Hawaiian lowland wet forest
I	Invasive
IPR	In progress review
K	Potassium
K-12	Kindergarten through twelfth grade
KCL	Potassium chloride
KITV	Hawaiʻi news station
KMR	Keaukaha Military Reserve
LAI	Leaf Area Index
LMA	Leaf mass per area
LWC	Leaf water content
LWF	Lowland wet forest
LWR	Leaf weight ratio
M	Molar
Mg	Magnesium
N	Nitrogen
N	Native
NIS	Non-native invasive species
NRCS	Natural Resources Conservation Service
P	Phosphorus
PCA	Principal Components Analysis
PH	A measure of the acidity or alkalinity of a solution
PIPES	Pacific Internship Program for Exploring Science
PVC	Polyvinyl chloride
R	Computer programming language
R:FR	Red:far-red ratio
REST	Restoring Ecosystem Services Tool
ROD	Rapid Ohia death
SAB	Science Advisory Board
SE	Standard error
SSD	Stem specific gravity

TCBES	Tropical Conservation Biology and Environmental Science
TEEB	The Economics of Ecosystems and Biodiversity database
TNC	The Nature Conservancy
UHH	University of Hawaiʻi at Hilo
US	United States
USDA	United States Department of Agriculture
WUE	Water-use efficiency
$\delta^{13}C$	Delta Carbon 13

Keywords
Carbon turnover rates, community assembly, complementary, ecosystem services, functional traits, hybrid ecosystem, invasion resistance, redundant

Acknowledgements
We thank the Strategic Environmental Research and Development Program for funding (Project RC-2117). Access to field sites was provided by the County of Hawaiʻi, Division of Forestry and Wildlife, and Hawaiʻi Army National Guard. The authors recognize staff, students, and interns (listed within this report) from the University of Hawaiʻi and the USDA Forest Service Institute of Pacific Islands Forestry for logistical and technical support. We thank our partners in the Hawaiʻi Army National Guard Environmental Office (Angela Kieran-Vast, Craig Blaisdell, and Kristine Barker) and staff at Keaukaha Military Reservation for facilitating the establishment of the Liko Nā Pilina project.

Abstract:
RC-2117

Objectives: This study, using a hybrid ecosystem approach, was designed to test whether hybrid ecosystems can 1) maintain themselves with relatively little input; 2) are capable of sequestering substantial amounts of carbon; 3) sustain a broad range of native biological diversity; and 4) remain open enough at ground level to allow human movement through them. We expect our results will directly benefit the military mission in the Pacific. Currently the prevalence and dominance of invasive species in DoD lands in Hawaiʻi and the Pacific has precluded the ability to effectively use the landscape for necessary training maneuvers. Hybrid ecosystems are an approach to allow training while still protecting endangered species and their associated environments.

Technical Approach: Our objectives were addressed and tested in the lowland wet forest at the Keaukaha Military Reservation on the Island of Hawaii. The application of functional trait theory in restoration and management is an exciting new approach that can be used to understand the persistence of species and ecosystems – and to build model communities with desired ecosystem functions. In this project a functional trait based restoration approach was used to select the native and non-native species for the hybrid communities planted. Principal components analysis was implemented to design communities that foster slow and moderate carbon turnover rates and also test ecological theory concerning complementary and redundant trait space within plant communities. We hypothesized that this higher functional diversity will be advantageous in the goals of higher carbon sequestration and higher resistance to weed invasion, which should lead to a lower understory cover that fosters native regeneration and allows for the greater human mobility required for military training. Surveys of abiotic (i.e., leaf area index, canopy openness, soil nutrient availability) and biotic (i.e., tree basal area and density) parameters were measured across the twenty plots prior to clearing of invasives and the planting of the experimental treatment communities. Monitoring of abiotic and biotic (i.e., tree growth and survival, native seedling regeneration, litterfall inputs, litter decomposition rates, seed rain, reproductive phenology, carbon sequestration and resistance to weed invasion) parameters were continued post-planting, along with mechanical methods of plot maintenance. The REST computer program was developed to provide a user friendly tool for those wanting to implement a functional trait based restoration strategy to degraded ecosystems.

Results: The early results of this experiment show that the treatments have a drastically different environment than the invaded reference condition, with large increases in light availability and recruitment of new individuals. Specifically, natives and non-natives were found to occupy separate trait space when evaluated with the principal components analysis; natives tended to have higher values of foliar C:N and leaf mass per area, and smaller values for foliar N, seed mass, leaf area, and maximum height. Invasives overlapped trait space of both natives and non-natives. The twenty plots were similar in the abiotic and biotic parameters measured prior to applying the experimental treatments. Yet, pre-removal native species density, LAI, canopy openness, soil carbon and soil sodium differed significantly between the plots. To evaluate the impact of this restoration approach on ecosystem services we projected values of carbon and biodiversity using a return on investment approach. When accounting for estimated expenditures

over longer terms, project return on investment varied based on carbon storage income as well as including or excluding biodiversity from income. With higher carbon market rates and a favorable labor decrease (25% of current rates), stored carbon alone presents an investment return of approximately 56 years. Including biodiversity results in an economic recovery period of approximately 45 years, supporting our objectives within a 50-year management timeframe.

Benefits: Our results are applicable throughout LWF in Hawaiʻi. Most importantly, our results will directly help the military meet the stewardship responsibilities of Army National Guard land by providing guidance on species choice in restoration. The approach could be applied to other heavily-invaded DoD sites to guide these areas toward lower intensity, more sustainable, and cost-effective management in the long-term. With REST, there is the ability to test in other ecosystems the four restoration objectives currently described within the program: successional facilitation, fire tolerance, drought tolerance, and carbon storage.

1. Objectives

Project Number RC-2117 addresses one of the major objectives of SON number SISON-11-83 in lowland wet forests, at the Keaukaha Military Reserve (KMR) on the Island of Hawaiʻi:

> *Identify or develop as necessary the suite of silvicultural practices that when appropriately implemented improves life-cycle carbon management, especially storage, while sustaining other desired ecosystem services, such as mission support, and maintenance of native biodiversity at different spatial scales (Objective 4, SISON-11-03).*

The project develops and evaluates a set of hybrid ecosystems, in which native and non-native species mixtures provide valuable forest structure and ecosystem services. The Hawaiian name, *Liko Nā Pilina*, translates to growing/budding new relationships, and reflects the species interactions likely to develop out of these new mixtures. We developed this approach because in some areas, such as Hawaiʻi, colonization by non-native species is so pervasive that often we cannot go back to all-native ecosystems on anything but the smallest scale, either economically or practically. Furthermore, some non-native species may be playing important roles in the community in terms of providing ecosystem goods and services. Our long-term project goals are to test whether hybrid ecosystems can 1) maintain themselves with relatively little input; 2) are capable of sequestering substantial amounts of carbon; 3) sustain a broad range of native biological diversity; and 4) remain open enough at ground level to allow human movement through them.

Following the advice of the SAB, our project was broken up into two phases. In Phase 1, we focused on analysis of the functional traits of candidate species that were capable of surviving in lowland wet forest (LWF) habitats. We surveyed remnant LWF in east Hawaiʻi Island and used that information to develop a quantitative methodology for deciding on the experimental treatments (mixtures of species based on functional trait combinations). In Phase 2, we set up and monitored, and evaluated the experiment (Figure 1). Toward that end, our project followed a set of tasks (Table 1) during the 5.5 year period from April 2011 to Oct 2016.

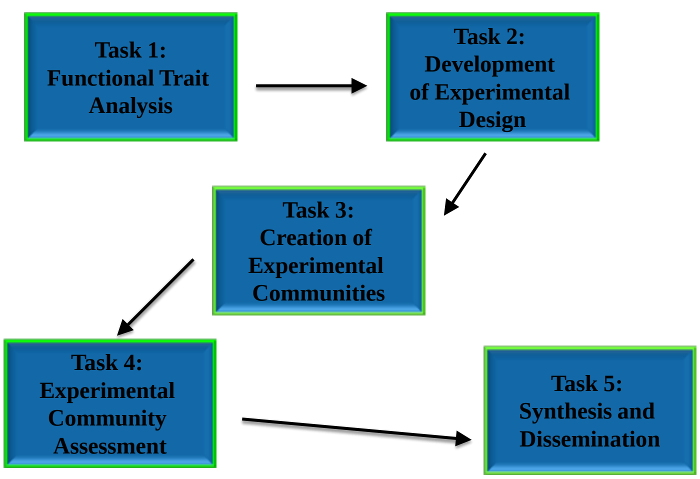


Figure 1. *Conceptual workflow of Project RC-2117, the Liko Nā Pilina project.*

1.1 Determine the functional trait profiles of Hawaiian lowland wet forest species.

a) *How do native Hawaiian LWF species and additional non-native species vary in their functional trait profiles?*
b) *What traits are most important in differentiating these species?*

1.2 Design combinations of species that will serve as self-sustaining hybrid ecosystems, balancing tradeoffs between supporting native biodiversity and human needs for C storage and military training.

a) *What combinations of species best maximize carbon (C) storage and minimize C turnover, provide the most benefits for native plant biodiversity, and allow for open understory structure with high invasion resistance (i.e., little non-native invasive species (NIS) cover) that is suitable for dismounted jungle military training?*
b) *Will a mixture of native and non-native species, selected on the complementarity or redundancy of their functional trait profiles, provide desired ecosystem services? How do these experimental communities compare, in regards to the ecosystem services they provide, to the present (highly invaded) forest condition?*

Table 1. *Task structure for RC-2117, the Liko Nā Pilina project.*

Main Task	Sub-Task (Milestone)	Start Year
1. Functional Trait Analysis	1.1 Finalize research agreements and hire personnel	2011
	1.2 Complete list of candidate species	
	1.3 Literature review	
	1.4 Field measurements of traits	
	1.5 Analysis of functional trait data	
2. Development of Experimental Design	2.1 Classification of candidate species	2012
	2.2 Decision of species mixtures made	
	2.3 Decision on plot size and replicate quantity made	
3. Creation of Experimental Communities	3.1 Plot locations established	2012
	3.2 Survey of pre-treatment biotic and abiotic parameters	
	3.3 Outplant collection and greenhouse preparation	
	3.4 Field manipulations	
	3.5 Outplanting of species	
4. Experimental Community Assessment	4.1 Decomposition experiment	2013
	4.2 Data collection and analysis	
5. Synthesis and Dissemination	5.1 Development of generalizable model	2015
	5.2 Workshop for end users	
	5.3 Development of user guide	
6. Submission of Technical Reports to SERDP	6.1 Draft Phase I Interim Report	2012
	6.2 Draft Phase II Interim Report	
	6.3 Draft Users Guide	
	6.4 Draft Final Report	
	6.5 Final Report	

2. Background

Restoration, in its broadest sense, involves improving conditions at a site to meet desired objectives. Traditionally, improving site conditions has meant an effort to return to a former, less disturbed state and much has been learned by examining recovery rates across ecosystem types (e.g., Rey Benayas et al. 2009). However, the "unfortunate reality" (sensu Hobbs et al. 2014) is that, in an increasing number of ecosystems, it is not feasible to return to a previous state for reasons that include the lack of reference sites or historic baseline conditions, irreversible climate change, and colonization by highly invasive non-native species that cannot practically be removed (Zedler et al. 2012).

Such is the case in Hawaiian lowland wet forests—a habitat with only a small portion of its original range left and in which highly invasive species are now predominant (Zimmerman et al. 2008). The Hawaiian Islands are an extreme case study for biological invasion; approximately half of the flora is non-native (Wagner et al. 1999) and a number of invaders have been shown to have strong ecosystem-level effects on carbon and nitrogen cycling and native biological diversity (e.g., Vitousek and Walker 1989, Hughes and Denslow 2005, Litton et al. 2006). A combination of events have led to systematic alteration of low elevation lands, including: 1) small-scale clearing and burning for agriculture and housing by Hawaiians prior to European contact (Kirch 2002); 2) large-scale clearing for sugarcane agriculture (Cuddihy & Stone 1990); 3) planting and aerial seeding of non-native trees by territorial foresters, due to a lack of understanding about native forest function (Woodcock 2003); and 4) intentional and accidental introduction of many alien plants and animals that benefited from a mild climate, limited interspecific competition, and enemy release (Denslow 2003). The result is a series of communities dominated by mixtures of species that share no evolutionary history, and which contain high proportions of non-native species classified as invasive. In these highly altered habitats, we have no clear historical guide of what species should be planted to achieve traditional restoration goals, and furthermore it has become clear that maintaining these forests as all-native species assemblages is unsustainable in terms of manpower, logistics, and cost (Ostertag et al. 2009; Cordell et al. 2016).

In some of these situations, a viable option may be to conduct functional trait based restoration. That is, to seek to restore some degree of ecosystem functionality, structure and ecosystem services (sensu Ostertag et al. 2015), even though the outcome may lead to a new ecosystem state (or novel ecosystem), rather than a return to former (and generally unattainable) conditions. Functional trait-based restoration can involve the use of species not originally found in a given site—including exotic species (Ewel & Putz 2004; Schlaepfer et al. 2011)—guiding the biodiversity towards more favorable species assemblages. The application of functional trait theory in restoration and management is an exciting new approach that can be used to understand the persistence of species and ecosystems – and to build model communities with desired ecosystem functions.

Functional trait-based restoration is based on the principle that ecosystem function depends in part on the expression of various morphological, structural, physiological, or chemical traits of organisms as well as environmental filters and the interaction between traits and the environment. Functional traits reflect fundamental life history and resource use tradeoffs (Reich

et al. 2014). Because these traits vary predictably across environments, it is assumed that they are the products of natural selection. For plants, the role of natural selection is supported by global datasets that show how plant traits vary continuously along abiotic resource availability gradients and across biomes (Wright et al. 2005; Chave et al. 2009; Donovan et al. 2011; Reich 2014). Evolutionary tradeoffs faced by organisms in resource acquisition (e.g., light, water, and nutrient uptake) and resource processing (e.g., net primary productivity) result in different ways to make a living, which Reich (2014) termed the "the world-wide 'fast–slow' plant economics spectrum." Plant species on the slow end of the spectrum have low rates of resource acquisition and processing, which requires leaf, stem, and root traits that are more conservative and efficient in resource use than plant species on the fast end of the spectrum. Being a slow species is advantageous under low-resource conditions because resource conservation traits enhance survival, but being a slow species can be a drawback under higher-resource conditions. In a given biome, there is selection for trait convergence, but within a more localized community, it is likely that interspecific competition ensures that species vary along the slow-fast continuum (Reich 2014). Thus, at the community and ecosystem levels, functional traits help explain the distribution of species, the assembly of communities, and the rate of ecosystem processes (Reich et al. 1999; Reich et al. 2003; Reich 2014).

At the community level, the functional trait profiles of species can be represented by functional diversity. Simply put, functional diversity is a way to define diversity of species traits within a community or ecosystem, encompassing metrics that focus on the magnitude, variation, and dissimilarity in species' functional traits (Schleuter et al. 2010). Considering functional diversity rather than species diversity may be a more promising approach for addressing questions of how species influence the structure and function of ecosystems (Laureto et al. 2015) or community assembly (Bhaksar et al. 2014).

Therefore, selecting species for restoration projects that have a specific set of trait values should influence competitive interactions, resource availability, and ecosystem structure and functioning. Ideally, these functional traits should be easily defined and measured, so that the approach is transportable and flexible and the predicted successional outcome of restoration can be tested (Ostertag et al. 2015). For example, selecting species with a broad range of functional traits (i.e., low niche overlap or inversely high functional divergence) may preclude exotic species from invading if their functional trait values are already represented in the community (Funk et al. 2008).

If the experimental communities are effective, they could be scaled up across KMR to facilitate military training. Additionally, our study's overall success could have far reaching implications, as this functional trait based approach could be used worldwide in other "unfortunate reality" situations.

3. Materials and Methods

3.1 Functional Trait Profiles of Lowland Wet Forest Species in East Hawaiʻi

The process of developing the treatments was described in Ostertag et al. (2015) and is summarized here. To choose species for the experiment, in 2011 we developed a list of candidate species capable of surviving in lowland wet forest (LWF) environments in east Hawaiʻi Island. We defined LWF as < 700 m elevation and greater than 2500 mm rainfall (Price et al. 2007). These climatic conditions are compatible with the study site where the hybrid ecosystem experiment was conducted. All sites are on substrates from Kilauea and Mauna Loa volcanoes. As these are the two youngest volcanoes in the archipelago, flow ages ranged from less than 200 years before present to *ca.* 5000 years old (Trusdell et al. 2005). The geographic location of the study sites are in Figure 2 and their climate and lava age details are in Table 2.

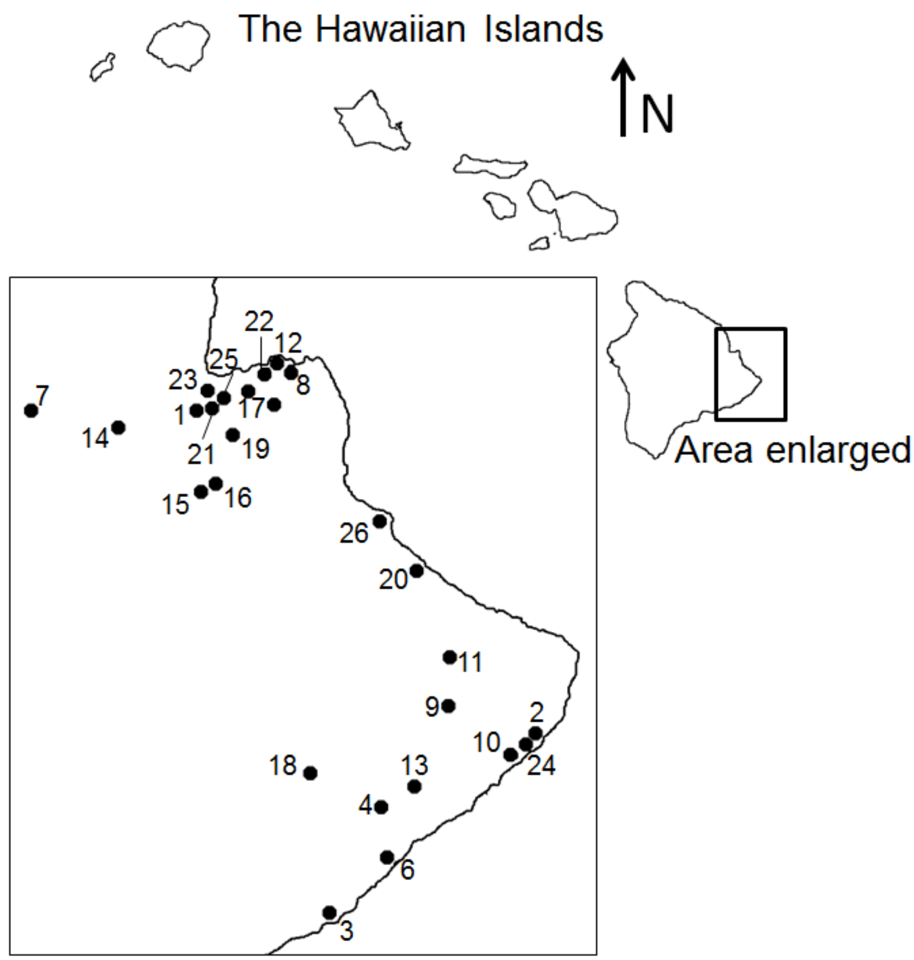


Figure 2*. Location of sampling sites for functional trait analysis. Site numbers correspond to those in Table 2.*

The candidate species list (Table 3) included both native species and non-native species that were deemed non-invasive, based on Hawai‘i Weed Risk Assessment score (Daehler et al. 2004, www.botany.hawaii.edu/faculty/daehler/wra/full_table.asp.html) and our personal experience in the field. In addition, we measured some highly invasive species in LWF to learn about their role in the community—their dominance has a strong influence on current functioning and trait diversity of the present invaded forest (Cordell et al. 2009, Ostertag et al. 2009). The majority of these were woody species, but two native species of tree fern, two palms and one arborescent monocot (*Pandanus tectorius*) were also included because of their prevalence and ecological significance in HLWF.

Table 2. *List of sites where plant traits were collected. Lava flow ages from Trusdell et al. (2005). Rainfall from Giambelluca et al. (2013). Species abbreviations follow Table 3.*

Site #	Site Name (Code)	Lava Flow Age (Years)	Rainfall (mm)
1	Institute of Pacific Islands Forestry	≤ 200	3907
2	Isaac Hale Beach Park	400-750	2227
3	Kalapana private land	1500-3000	2009
4	Keau‘ohana Forest Reserve	200-400	2844
5	Keaukaha Military Reservation	750-1500	3338
6	Keokeo Loop	≤ 200	2929
7	Kīpuka 10.5	3000-5000	5995
8	Lālākea Beach Park	750-1500	3338
9	Lava Trees State Park	≤ 200	3151
10	Malama-Ki Forest Reserve	≤ 200	2345
11	Nānāwale Sea View	≤ 200	3099
12	Onekahakaha Beach Park	750-1500	3285
13	Pu‘u Kali‘u	400-750	2765
14	Puainako Extension	750-1500	5332
15	Stainback Hwy Quarry Rd	750-1500	4166
16	Waiākea Forest Reserve	750-1500	4154
17	Wailoa River State Park	750-1500	3496
18	Wao Kele ‘O Puna	350-500	3464
19	Hilo Site 1	750-1500	3690
20	Hawaiian Paradise Park	≤ 200	3114
21	‘Imiloa	≤ 200	3803
22	Keaukaha Beach Park	750-1500	3287
23	Hilo Site 2	750-1500	3614
24	Pohoiki Cemetery	200-400	2303
25	University of Hawai‘i at Hilo	750-1500	3716
26	Puna coastal sites	750-1500	3142

Table 3. *Master list of species with species abbreviation codes used in text. Included species are those whose functional traits were measured at sites listed in Table 2 to assist with species choice for the development of the experiment. Some of the species ended up in the experiment as core, trait, or existing species in the experiment. Species are categorized by their origin (native (N), exotic (E), invasive (I)). For the purposes of the experiment, the two Cibotium tree fern species were considered as one species.*

Species Code	Scientific Name	Family	Origin	Core Species	Trait Species	Existing Species
ANPL	*Antidesma platyphyllum*	Phyllanthaceae	N		X	
CIME/CIGL	*Cibotium menziesii/glaucum*	Cibotiaceae	N		X	X
DISA	*Diospyros sandwicensis*	Ebenaceae	N			X
MEPO	*Metrosideros polymorpha*	Myrtaceae	N			X
MESP	*Melicope* sp.	Rutaceae	N			
MYLE	*Myrsine lessertiana*	Myrsinaceae	N	X		X
PATE	*Pandanus tectorius*	Pandaceae	N	X		X
PIAL	*Pipturus albidus*	Urticaceae	N		X	X
POHA	*Polyscias hawaiensis*	Araliaceae	N		X	
PSHA	*Psychotria hawaiiensis*	Rubiaceae	N			X
PSOD	*Psydrax odorata*	Rubiaceae	N	X		
PRBE	*Pritchardia beccariana*	Arecaceae	N	X		
RHSA	*Rhus sandwicensis*	Anacardiaceae	N		X	
WIPH	*Wikstroemia phillyreifolia*	Thymelaeaceae	N			
ALMO	*Aleurites moluccana*	Euphorbiaceae	E		X	
ARAL	*Artocarpus altilis*	Moraceae	E	X		
BRPA	*Broussonetia papyrifera*	Moraceae	E			
CAIN	*Calophyllum inophyllum*	Clusiaceae	E	X		
CONU	*Cocos nucifera*	Arecaceae	E		X	
COSU	*Cordia subcordata*	Boraginaceae	E			
MAIN	*Mangifera indica*	Anacardiaceae	E	X	X	
MOCI	*Morinda citrifolia*	Moraceae	E		X	
PEAM	*Persea americana*	Lauraceae	E		X	
PLRA	*Plumeria rubra*	Apocynaceae	E			
SASA	*Samanea saman*	Fabaceae	E	X		
SYMA	*Syzygium malaccense*	Myrtaceae	E		X	
TECA	*Terminalia catappa*	Combretaceae	E		X	
THPO	*Thespesia populnea*	Malvaceae	E		X	
ALAL	*Alexandria alexandre*	Arecaceae	I			
AREL	*Ardisia elliptica*	Myrsinaceae	I			
CEOB	*Cecropia obtusifolia*	Urticaceae	I			
CLHI	*Clidemia hirta*	Melastomataceae	I			
FAMO	*Falcataria moluccana*	Fabaceae	I			
FIMI	*Ficus microcarpa*	Moraceae	I			
MAMA	*Macaranga mappa*	Euphorbiaceae	I			
MESE	*Melastoma septemnervium*	Melastomataceae	I			
MEUM	*Melochia umbellata*	Malvaceae	I			
MICA	*Miconia calvescens*	Melastomataceae	I			
PSCA	*Psidium cattleianum*	Mytraceae	I			
PSGU	*Psidium guajava*	Myrtaceae	I			
SCAC	*Schefflera actinophylla*	Araliaceae	I			
SYCU	*Syzygium cumini*	Myrtaceae	I			
TROR	*Trema orientalis*	Ulmaceae	I			

We used a combination of field methods and literature review to develop a matrix of functional trait data for all species. We followed standardized protocols for the field and lab measurements (Cornelissen et al. 2003). Functional traits surveyed included: leaf area, leaf mass per area (LMA), total dry matter content, foliar nutrients (N, C, P), $\delta^{13}C$ (integrated water-use efficiency), photosynthesis and conductance rates, petiole length ratio, leaf arrangement, stem wood specific gravity, canopy stature, elevational range, maximum height, vegetative spread, seed mass and an index indicating canopy breadth of adult plants in relation to the relative density of shade cast. If a species was found in multiple environments (e.g., on different aged lava flows), we sampled in these different environments. At each site we attempted to sample at least 10 individuals per species for leaves and stems, and 10 leaves per each one of these individuals.

In the field, we collected ten to 15 mature sun leaves and a stem or branch cutting from each individual, except when it was logistically impossible (i.e., limited by plant height) or ethically unadvisable (e.g., when cutting a stem would kill a native plant considered to be rare). For each plant we recorded individual crown depth (which related branch arrangement at different bole heights) and relative stature within the canopy (understory, midstory and overstory). We measured conductance and photosynthetic capacity (A_{max}) in the field using a LI-6400 portable photosynthesis system (LI-COR Inc., Lincoln, NE). Both of these measures were taken on two sun leaves per each of five individuals per species (and were used in turn to calculate water-use efficiency (WUE). Data regarding maximum height and seed mass were obtained from the literature.

Because of the profusion of shrubby species, the variability of abundance in the field, and the relative rarity of some of the species sampled, we measured branch specific gravity (BSG; following Swenson and Enquist 2008) rather than taking core samples from a central stem to obtain stem specific gravity (SSD). All BSG measurements were cross-checked against previously reported SSD values in the literature, and were found to be generally congruent. SSD values for tree ferns, *Pandanus tectorius* and *Pritchardia beccariana* were taken from the literature, given that these are arborescent species that lack true “wood” or branches.

In the lab, functional trait measurements followed protocols outlined by Cornelissen et al. (2003), aside from removing petioles before taking measurements of leaf area and leaf mass. Leaf thickness was measured using a Mitutoyo PK-0505 digital micrometer (Mitotoyo Corporation, Kawasaki, Japan) and leaf area was measured on a LI-3100 leaf area meter (LI-COR Inc., Lincoln, NE). Leaf samples were weighed before and after drying at 70˚C for at least 48 hours. Raw leaf measurements were used to calculate the leaf length-to-petiole ratio (cm/cm), leaf mass per unit area (LMA; g/cm^2) and leaf water content (LWC; percentage) for each of the leaves measured. Because of the size of their leaves (or fronds), we did not collect whole leaves from tree ferns, *Pandanus tectorius* or *Pritchardia beccariana*, but rather subsampled leaves to obtain foliar chemistry data. Measures of total leaf area for these species were estimated as being over an order of magnitude larger than the largest leaf area measured for any other species. The standard value used was 1500 cm^2, since the largest leaf area measured among the other species was 135.38 cm^2.

Dried leaf samples were ground in a Wiley mill using the 40-mesh filter and chemical analyses were carried out at the analytical laboratory at the University of Hawaiʻi at Hilo. Foliar carbon (C) and nitrogen (N) were determined by combustion on a Costech 4010 Elemental Analyzer

(Costech Analytical Technologies, Valencia, CA). To obtain foliar phosphorus (P) measurements, samples were dry ashed at 500°C for 5.5 hours, then dissolved in 1M HCl and analyzed using a Varian Vista MPX ICP-OES (Varian Analytical Instruments, Walnut Creek, CA). Analyses of foliar carbon, nitrogen, C:N and P were carried out at the out at the analytical laboratory at the University of Hawaiʻi at Hilo.

One of the simplest ways to categorize species based on their functional characteristics is to use multivariate analysis to place each species in trait space (Ostertag et al. 2015). We used principal components analysis (PCA) – a multivariate tool that allows us to synthetically address and compare the role of multiple variables, in this case functional plant traits, rather than address each variable independently (Peck, 2010). A multivariate approach is particularly useful when analyzing suites of plant traits because correlations and allometric relationships exist between many of the metrics (e.g., leaf construction and stem or petiole construction are not entirely independent of each other). Trait data were collated by species, which involved averaging values across sites and replicates. Mean species values were assigned to quartiles in order to make these values comparable on a similar scale. By using quartiles we were also able to capture important information, such as which species had the highest and lowest values for any given trait, while avoiding the pitfalls of normalizing skewed data which varied several orders of magnitude. For example, seed mass alone varied by at least six orders of magnitude. We examined the function trait data in several different ways by running separate PCAs—with only native species, with native and exotic species, and with native, exotic, and invasive species.

3.2 Using Functional Trait Data to Design the Experiment

With the PCAs in hand (see Section 4.1), we were able to design a methodology for choosing the experimental treatments to be implemented at the study site (see Section 3.3). We used a second PCA (Figure 3) based on traits related to carbon to select species whose ecological strategies reflect either slow or moderate rates of carbon turnover (e.g., species with dense wood, slow decomposition and slow growth versus species with faster growth and decomposition as well as lighter wood). Two native and two non-native species were chosen as core species for each of the two carbon treatments. These core species are the largest trees that anchor the treatment. Considering that the study site at KMR currently contain two native canopy dominant species (*Metrosideros polymorpha*, *Diospyros sandwicensis*), these two species were excluded from being core species.

In a broader sense the core species represent different positions on the "the world-wide 'fast–slow' plant economics spectrum" (Reich 2014). Plant species on the slow end of the spectrum have low rates of resource acquisition and processing, which requires leaf, stem, and root traits that are more conservative and efficient in resource use than plant species on the fast end of the spectrum. Being a slow species is advantageous under low-resource conditions because resource conservation traits enhance survival, but being a slow species can be a drawback under higher-resource conditions. In a given biome, there is selection for trait convergence, but within a more localized community, it is likely that interspecific competition ensures that species vary along the slow-fast continuum (Reich 2014). Thus, at the community and ecosystem levels, functional traits help explain the distribution of species, the assembly of communities, and the rate of ecosystem processes (Reich et al. 1999; Reich et al. 2003; Reich 2014).

Among our core species, Slow turnover species (hereafter Slow) had traits that are associated with slow rates of growth and nutrient cycling: high leaf-to-petiole ratio, low leaf thickness, high specific gravity, low leaf area, low specific leaf area, slow rates of maximum photosynthesis, high rates of water-use efficiency, and short maximum height. Moderate turnover species (hereafter Moderate) had intermediate values for these traits. In this experiment, we did not choose species from the "fast" end of the spectrum because the overarching goal of the experiment is to design restoration treatments that slow down the rates of nutrient cycling, which is hypothesized to improve invasion resistance. Species with those trait values at the fast end of the economics spectrum tend to be invasive in Hawaiian lowland wet forests (Zimmerman et al. 2008; Ostertag et al. 2009).

After the core species were chosen, a second step was to display them in trait space on the original PCA (using all traits and not just traits related to carbon) (Figure 3). Their centroid was calculated. Then, the six remaining species in each treatment (Trait Species) were selected by calculating the centroid of the four core species, and then choosing species (based on Euclidean distances) that were either similar (near) in trait expression to the core species (Redundant) or different (far; Complementary) (Figure 3). We ran a functional dispersion test (FD package in R; Laliberté and Shipley, 2011) in order to validate our decisions and found that the complementary species mixes showed greater functional dispersion (0.325 and 0.318 respectively for Slow and Moderate) than did the redundant mixes (0.314 and 0.299 respectively).

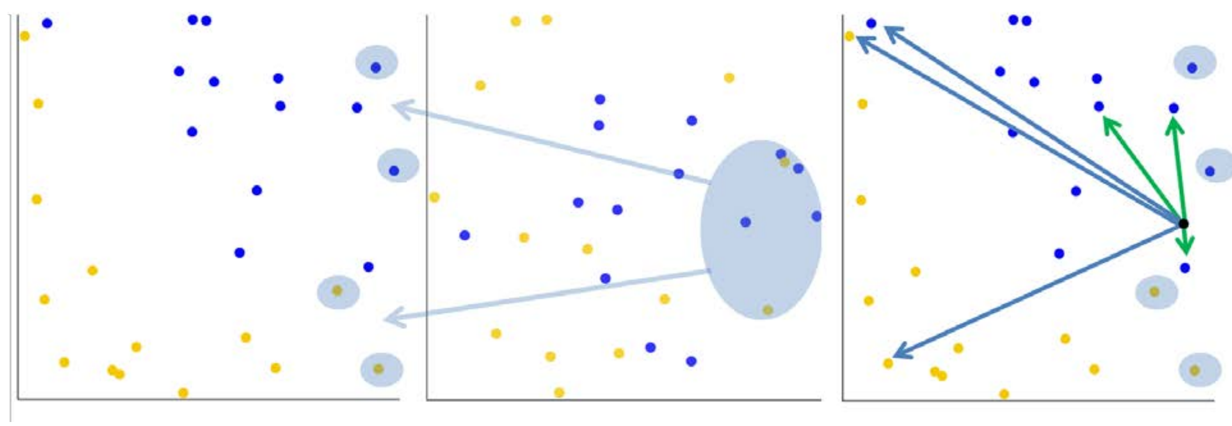


***Figure 3**. Overview of the ordination process used to select species. (a) Principal components analysis (PCA) showing all species: natives in blue and exotics in yellow. Species circled are the 'core species' identified in the second PCA as being species that can store C effectively. b) PCA highlighting carbon-related traits; the species circled are the ones selected for having slowest carbon turnover, according to their position in the PCA. c) On the main PCA, once a centroid has been found (center point between the four core species), species are identified as having redundant (similar – geometrically closest on axis 1) or complementary (less similar – geometrically distant on Axis 1) trait profiles.*

The emphasis on contrasting mixtures is motivated by research in grasslands that suggests that functional diversity may lead to increased invasion resistance (Funk et al. 2008, Hooper and Dukes 2010). Functional complementarity appears in communities where the number of functional niches occupied is maximized. This improves the diversity of resources available and the efficiency in their use (Northfield et al. 2010). Functional redundancy aims at having several species occupying the same or similar role in the community. Large functional redundancy will confer higher resilience to the community because the function of one species that is lost can be

covered by the redundant species (Walker 1992, 1995). However, the principal mechanisms affecting complementary vs. redundant communities are still unclear (Díaz & Cabido 2001).

The final experimental design selected for KMR consists of four experimental treatments (Slow Complementary, Slow Redundant, Moderate Complementary, Moderate Redundant) in which natives were left in place, all non-native species were cleared, and different mixtures of 10 species were planted (Figure 4). In addition, there is a Reference treatment (the invaded forest).

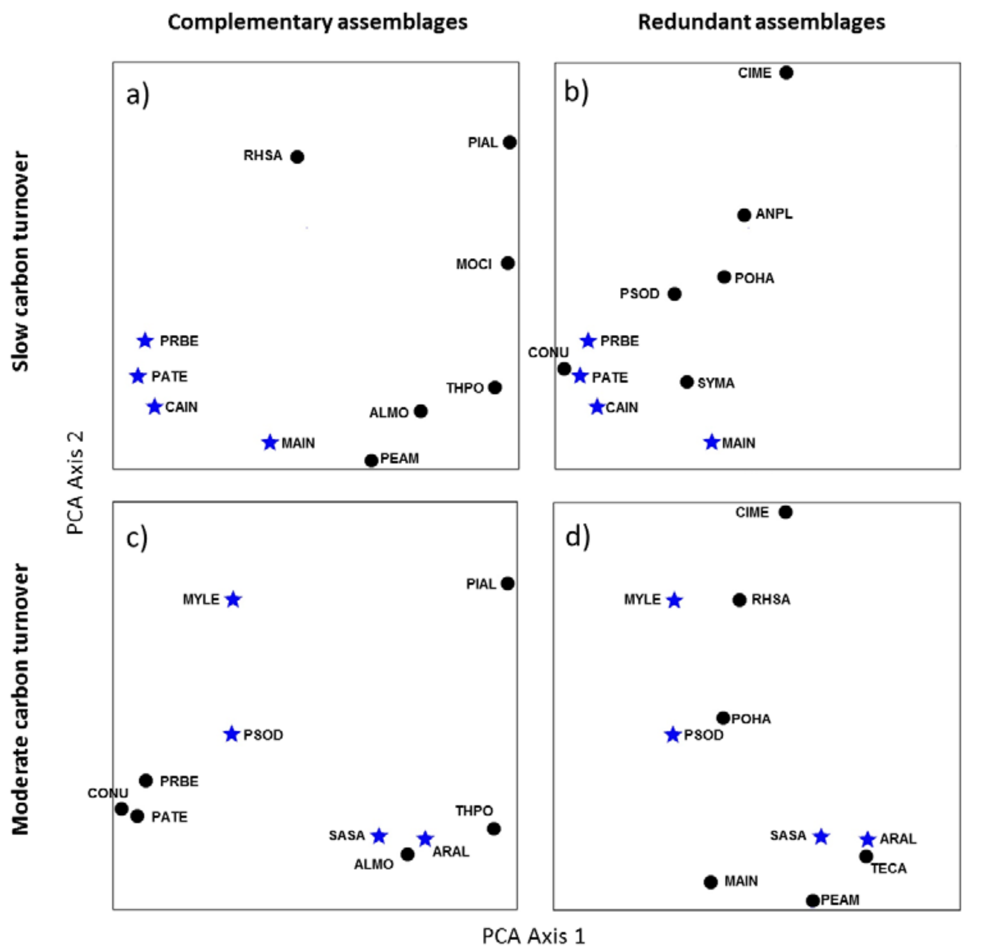


Figure 4*. The four experimental treatments of the Liko Nā Pilina experiment in east Hawai'i. The arrangement of species in 'trait space' was determined using PCA. Each treatment has 10 species, chosen for their C turnover rates (the four core species, represented by blue stars) and their functional trait values relative to other species (e.g., complementary or redundant). a) Slow Complementary, b) Slow Redundant, c) Moderate Complementary, and d) Moderate Redundant. Species abbreviations in Table 3.*

3.3 Study Site

The study site is a lowland (30 m.a.s.l.) wet forest at the Keaukaha Military Reservation (KMR, 19°42'15" N, -155°2'40" W) in Hilo, Hawai'i. A defining feature of the site is the substrate—an 'a'ā lava flow dated as 750-1500-yr-old. This substrate is extremely challenging for farming or mobility, and is the reason why the land was never cleared. Rainfall averages 3,347 mm/yr (Giambelluca et al. 2013) and mean annual temperature is 22.7 °C (Giambelluca et al. 2014).

The site contains native trees in the canopy and midstory, but these species are not regenerating under current conditions (Cordell et al. 2009). The site is heavily invaded by non-native trees and shrubs that make up approximately 45% of the basal area (Ostertag et al. 2009).

3.4 Plot Selection

To test our restoration objectives in the most promising sites, we located areas that had the greatest native canopy, identifying four separate areas (blocks) with appropriate forest conditions and terrain, and used surveying equipment to lay out five plots in each block (Figure 5). Assignment of treatments to plots was random. Each plot measures 20 x 20 m with a 5 m perimeter buffer. We aimed for a 10 m distance between the buffers for each plot, but actual distances depended on terrain and avoidance of gullies and treefall gaps.

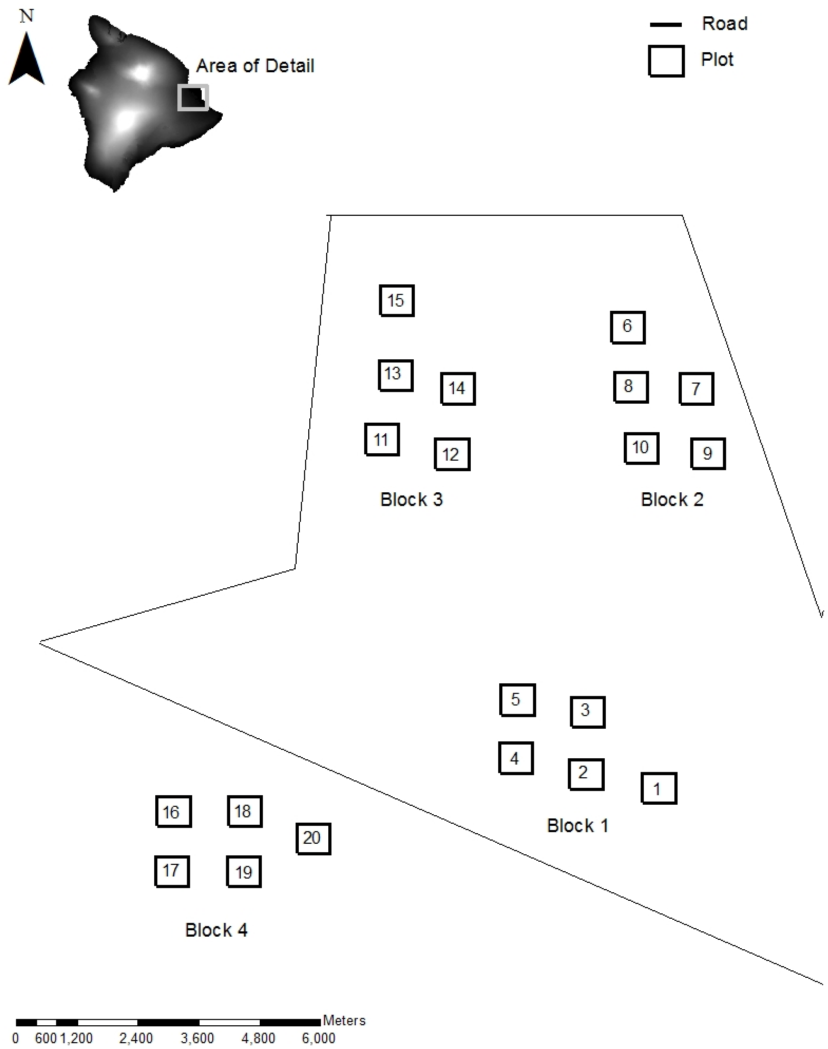


Figure 5. *Map of study site and experimental setup. For treatments assigned to each plot number see Table 6.*

During the 2016 IPR, the committee asked us to describe in the final report the process by which blocks were selected, and the degree to which quantitative measures were used. We used the best aerial photo map to look for sites. We also had done a previous experimental removal in 2004 four plots and we wanted to avoid those plots. Due to the need to chainsaw large trees and move the wood off the plot, we needed to be in areas that were not too long of a hike from roads. In addition, we needed to work around the planned dismounted training lanes, which were not fully completed when we starting creating the plots at KMR. These factors left us with a small forested area to consider (Figure 6). We chose our blocks by hiking within the remaining forest possibilities, looking for areas with the most intact native canopy that spanned the greatest distance. We looked for areas at least 100 m x 70 m in area. Unfortunately, the native canopy trees are quite patchy, and we feel confident that the four areas chosen were the best representatives, given these constraints.

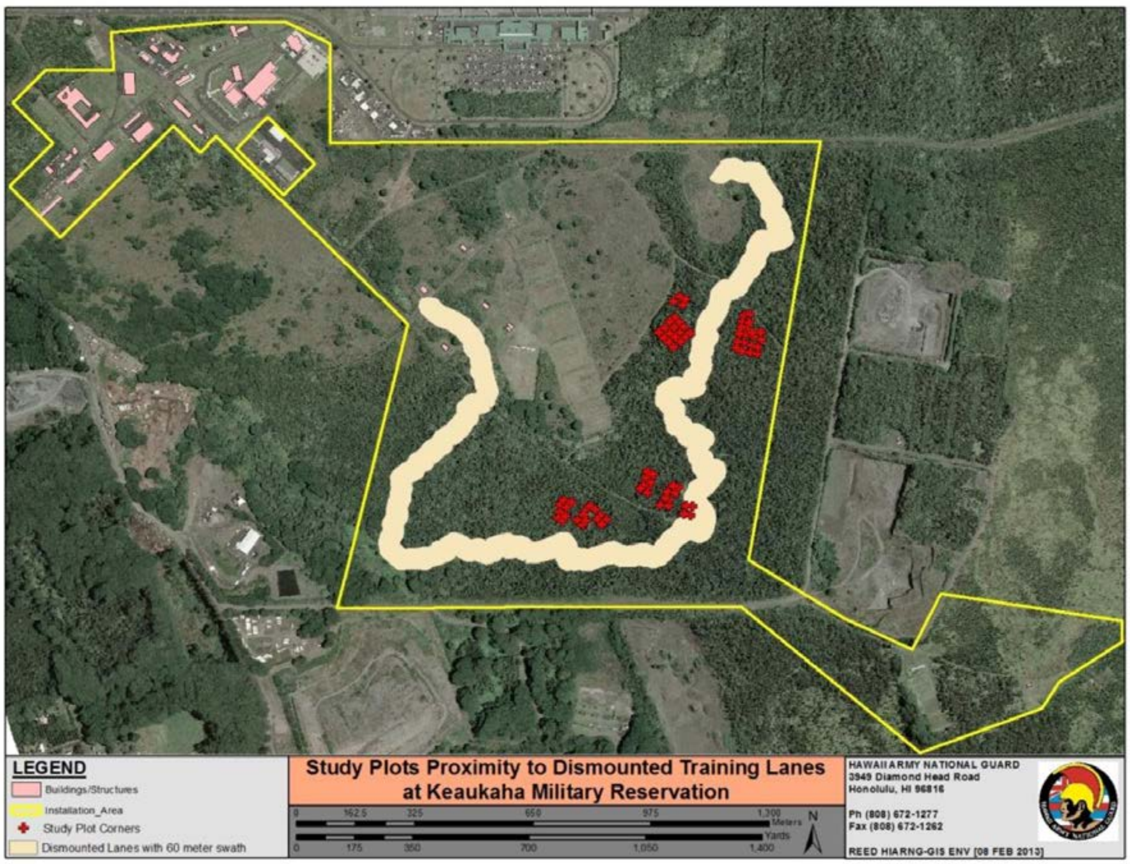


Figure 6. *Map of the KMR forested lands, in relation to the dismounted training lanes being built by the Hawai'i Army National Guard during the course of our project.*

3.5 Pre-treatment Measurements

Vegetation was surveyed in June-August 2012 using a modification of the methods in Zimmerman et al. (2008), which was a comprehensive survey of remaining Hawaiian lowland wet forests that included this site. Three types of measurements were taken in all 20 plots. For all trees with ≥ 2 cm diameter at breast height (1.3 m), DBH was recorded in the entire 400 m^2 area. For stems < 2 cm DBH, individuals/ha were counted in two subplots. If plants had multiple stems, all stems were included in the basal area, but the individual was only counted once for

density. Tree ferns (*Cibotium* genus) are important in terms of their contribution to native basal area and biomass, but prove to be problematic to measure. Hence their DBH was measured either at 1.3 m if the individuals were sufficiently tall, or at the highest point on the stem below the hanging fronds (because these tree ferns do not have significant taper; Ostertag et al. 2014) if they were shorter.

Soils were sampled in July 2012, using trowels to sample from no deeper than 10 cm (n = 4 per plot, with one sample in each subplot). It was impossible to get a volumetric soil core in the extremely rocky terrain so data are not expressed on an area basis. Roots and debris were hand picked out of soil samples to maintain soil aggregates. Soils were dried at 60 °C and ground. They were analyzed for carbon (C) and nitrogen (N) in a Costech 4010 Elemental Analyzer (Costech Analytical Technologies, Valencia, CA.), and for phosphorus (P) on a Technicon AutoAnalyzer AAI with parts from Pulse Instrumentation (Mequon, WI) after a modified Truog extraction. Cations were analyzed after ammonium acetate extraction on a Varian Vista MPX ICP-OES (Varian Analytical Instruments, Walnut Creek, CA). All laboratory analyses were done at the Analytical Laboratory at University of Hawai'i at Hilo.

Light availability was measured in two ways. In July 2012, in the early morning hours, we employed a LAI 2200 (LI-COR, Lincoln, NE), using a 45 degree cap. Four readings were taken from the center of each plot, one in each of the cardinal directions. At the same time, hemispherical photos were taken using a Canon EOS 5D camera and Canon EF 15 mm fisheye lens and photos were analyzed using WinsCanopy software (Regent Instruments, Inc., Quebec City, Canada).

3.6 Creation of Experimental Plots

Plots are 20 x 20 m with a 5 m perimeter buffer (n = 4/ treatment), arranged in a randomized block design. The four experimental treatments required clearing to remove all non-native species. Clearing of the plots and buffer zones (a 30 x 30 m area per plot, n = 16) began in late July 2012 and ended mid-April 2013. We removed all non-native species by hand-pulling, lopping, hand-sawing, or chain-sawing. Care was taken when felling trees to avoid crushing native vegetation, and challenging trees were guided with ropes while being felled. Introduced trees that were at least 50% rooted in a plot, or had a tree canopy that fell more than halfway into the buffer zone (2.5 m) were removed. Herbicide (30% Garlon 4 Ultra, mixed with 70% crop oil) was sprayed immediately onto cut stumps to prevent re-sprouting. All cut material was moved outside of the plots and buffer zones. Snags (in the canopy) were removed when they presented a safety concern, but otherwise dead wood was left in the plots. All native species (called existing trees, see Table 3) were flagged and not cleared, however their densities differed slightly between pre and post-clearing given 1) some limited damage of native trees during plot clearing, and 2) finding additional native plants once the non-natives were cleared.

All outplants were grown on Hawaiʻi Island from locally available propagules (either propagated by us or by local growers). Planting density was selected based on data from other Hawaiian lowland wet forests that have maintained a greater abundance of native species (Zimmerman et al. 2008), as well as the mature size of the plants. If a species was considered a large tree we planted five individuals per plot. Additionally, in each plot we planted 15 individuals per species of monocots (palms and pandans), ten individuals per species of medium trees, and 20

individuals per species of small trees, shrubs, and ferns. We made a few exceptions in order to balance overall planting numbers, densities, species distribution and sizes. The final number of plants per plot were: 125 for Slow Complementary, 130 for Moderate Complementary, and 120 for the two Redundant treatments.

In order to evenly distribute the plants across each plot we set up a grid across each 20 x 20 m planting area with a number of quadrats depending on the number of large tree species designated for that treatment (Figure 7). These large tree species served as foci, with other species planted around them in a stratified random design.

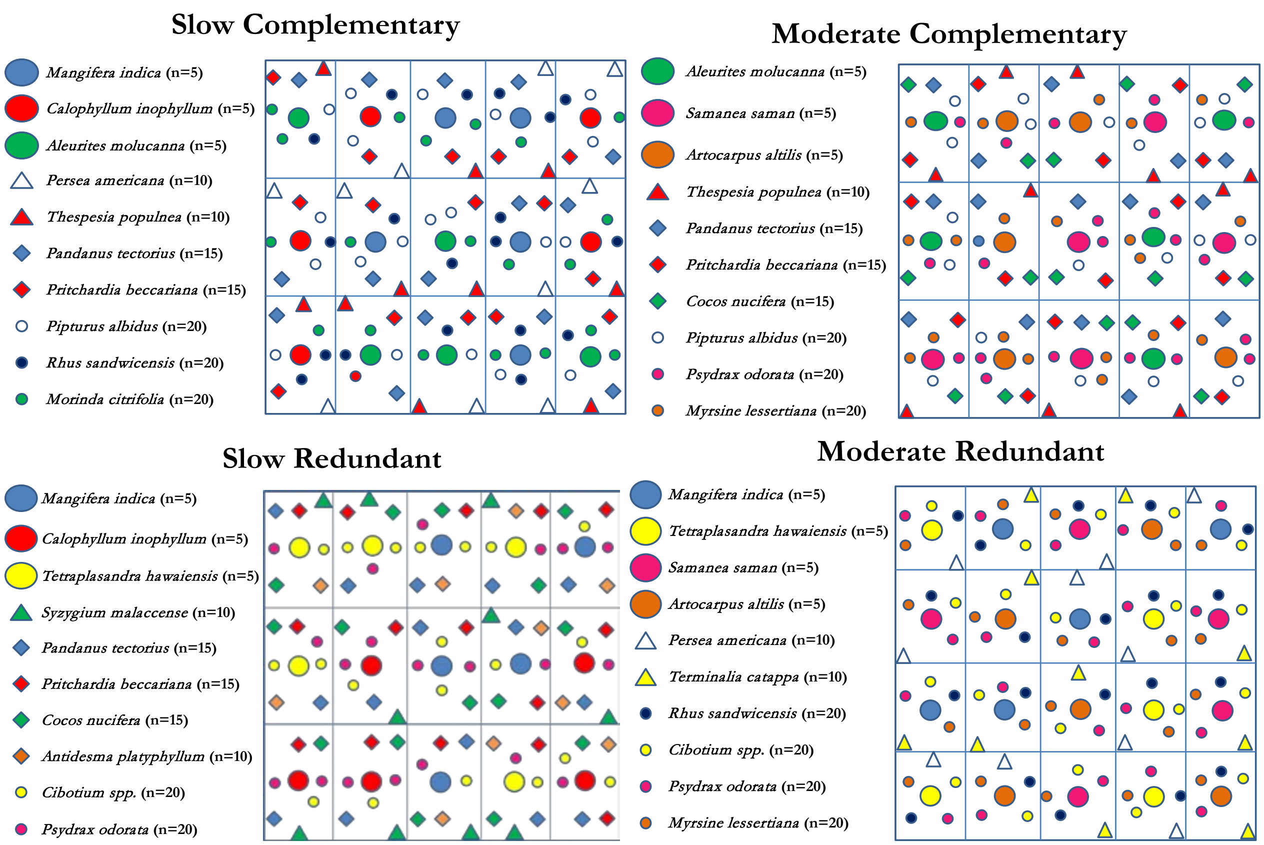


Figure 7. *Planting design for the four experimental treatments. Each design represents a 20 x 20 m plot and all treatments have 10 species. Size of the symbol relates to adult plant size. The Slow treatments have 125 individuals and the Moderate treatments have 120 individuals per plot. The design for the Slow Complementary, Slow Redundant, and Medium Complementary treatments is based on 15 smaller 6.6 m x 4.0 m quadrats, each with a central large tree individual and 8-9 surrounding plants. The Moderate Redundant treatment has 20 quadrats of 5.0 x 4.0 m size, with a central large species and 5 surrounding plants per quadrat. Note: Tetraplasandra = Polyscias (name change after figure was created).*

Plant spacing was based on adult plant size, such that large plants were placed 2 m away from their nearest neighbor, while medium and small plants were placed 1.5 m, and 1 m away respectively. When a pre-existing native tree was located where an outplant was supposed to be planted we relocated the outplants, making sure that no plant was placed < 1 m from any other plant. Plots were weeded before planting because several months passed after clearing, and new non-native seedlings popped up after the disturbance. Planting was done in stages from April

2013 to January 2014, because different species were ready to be transferred from nursery to the field at different times. Accordingly, we considered January 2014 as the beginning of the experiment. Some outplants of *P. tectorius* and *P. beccariana* were replaced a few months into the experiment, after the originals were dug up by feral pigs, but after that short period we did not do any more replacements.

From the moment plots were originally cleared, it was necessary to hand-weed at approximately 3-4 month intervals to sustain outplant growth. Vigorous post-clearing weed growth was expected, given that previous work at the site showed a largely non-native seed bank (Cordell et al. 2009). Stems that were too large to be managed by hand-pulling were cut with loppers and treated with herbicide. After the first year, we decided it was not feasible to hand weed the full 30 x 30 m area, and began weedwhacking the buffers, taking great care to avoid impacts on any natives or outplants.

3.7 Treatment Monitoring

The experimental measurements commenced in January 2014, and includes abiotic (leaf area index, canopy openness, soil nutrient availability), biotic (tree growth and survival, native seedling regeneration, litterfall inputs, litter decomposition rates, seed rain, flowering and fruiting phenology, carbon sequestration, resistance to weed invasion), and labor measurements (Table 4).

Table 4. *The regular measurements presently undertaken in the Liko Nā Pilina Experiment.*

Sampling Task	Frequency
Person-hours in field or lab	Daily
Litterfall (sorted into species)	Monthly
Seed Input (sorted into species)	Monthly
Phenology (presence/absence of flowers/fruits)	Monthly
Growth and survival rates of outplanted trees and recruiting sapling	Semi-annually
Seedling surveys	Semi-annually
Weed surveys	Semi-annually
Light measurements (hemispherical photos, LAI-2200, red:far red)	Semi-annually
Litter bags for decomposition rate	4 and 12 months
Growth and survival of native trees pre-existing in plots	Annually
Resin bags for nitrate, ammonium, and phosphate availability	Bi-annually

3.7.1 Light Availability

Light availability was measured in February 2014, February 2015, September 2015 and February 2016 using an LAI 2200 (LI-COR, Lincoln, NE), with a 45 degree cap. Four readings were taken from the center of each plot, one in each of the cardinal directions. At the same time (for all above time-points except September 2015), hemispherical photos were taken using a Canon EOS 5D camera and Canon EF 15 mm fisheye lens and photos were analyzed using WinsCanopy software (Regent Instruments, Inc., Quebec City, Canada).

A SKYE Instruments SKR 110 Red/far-red sensor was used to quantify light quality in the same quadrats as the seedling census. Light measurements were taken in four cardinal directions (N, E, S, W). The sensor was attached to a 50 cm PVC leveling arm, which was held in the center of the quadrat at 1 m height. Once leveled, the light quality reading (red-to-far-red ratio) was recorded,

and the leveling arm was then positioned and leveled in the next direction. The R:FR light quality readings were separated into three categories: low 0-0.4, medium 0.41-0.7, high 0.71-1.0.

3.7.2 Litterfall

Annual litterfall provides an estimate of productivity for each treatment. Litterfall collection using littertraps (collection area; 0.64 m^2 per trap) occurs at 20 locations per plot. Litter was collected monthly; beginning in January 2014. Each collection was dried at 70ºC for at least 48 hours and then weighed.

3.7.3 Nutrient Availability

In fall 2014, resin N and P (forms of these nutrients available for plant uptake) were determined by placing resin bags underneath an individual tree to assess that species' litter effects on soil nutrients. Individual trees will be followed over time. A given plot had 12 resin bags for N and 12 for P, planted under one tree per outplanted species, one *Metrosideros polymorpha* and one *Psychotria hawaiiensis*. Resin bags were placed in the plots along diagonal and crossed transect lines (n=20 per plot, 10 for Nitrogen analysis and 10 for Phosphorus analysis). Bags were 6cm x 7.5cm in dimension, constructed of 86 mesh silkscreen, and filled with 6g of mixed bed exchange resin. All vials and cups and material used for the resin bag process were acid washed in a 10% HCl acid bath and triple rinsed with Type 1 water. All sample bags were placed in the field on the same day and removed 30 days later. A 2.0 M KCl solution was used for the N extraction and a 0.5M HCl solution was used for the P extraction. Type 1 water was used for making the extract solutions. Resin bags were rinsed with Type 1 water to remove soil and debris from the bags and were extracted using 100mL of solution and placed on a Barnstead Max Q3000 lab shaker at 100RMP for 6 hours. Extract solutions were placed in 20mL scintillation vials and immediately frozen. P analysis is conducted on a Pulse Autoanalyzer III with Autosampler IV (Saskatoon, SK, Canada) and C and N is determined on a Costech Elemental Analyzer. All nutrient samples were analyzed at the University of Hawaiʻi at Hilo's Analytical Lab.

3.7.4 Species-level Responses

By May 2014 (4 months into the experiment) all existing natives with a DBH > 1.0cm and all outplants had been tagged and their locations within plots were mapped using ArcPad on Allegro MX field computers. Height class was recorded for the existing native trees (0-5, 5-10, 10-20, >20 meters). Outplant height was measured to the highest point. All stems >1.3 m height that had a DBH of at least 1.0 cm were measured for stem diameter to calculate basal area for each individual. Outplants have been re-measured at six month intervals (Dec 2014/May 2015) and existing trees on a yearly basis (May 2015). Status (alive or dead) is recorded at each census and percent survival calculated. Relative growth rates (RGR) were calculated using the following equation: $RGR\ (\%\ change\ per\ year) = (\ln(BA_1)-\ln(BA_0)/(t_1-t_0))*100*365$, where BA is basal area and t is time in days. In the case of individuals <1.3 m tall, height was substituted in order to calculate RGR. We present growth as % change (unitless) in order to compare across DBH and height measurements.

Outplant species that are expected to flower and fruit within the first couple years of the study were chosen to collect monthly phenology data; starting October 2014. The species chosen (n=9) at the slow complementary treatment were: *Calophyllum inophyllum, Aleurites moluccana, Rhus sandwicensis, Morinda citrifolia, Pandanus tectorius, Pipturus albidus, Mangifera indica,*

Persea americana, Thespesia populnea. The species chosen (n=7) at the slow redundant treatment were: *Calophyllum inophyllum, Syzygium malaccense, Psydrax odorata, Polyscias hawaiensis, Pandanus tectorius*, *Antidesma platyphyllum*, *Mangifera indica*. The species chosen (n=8) at the medium complementary treatment were: *Thespesia populneiodes, Pipturus albidus, Myrsine lessertiana, Pandanus tectorius, Samanea saman, Aleurites molucanna, Artocarpus altilis, Psydrax odorata*. The species chosen (n=9) at the medium redundant treatment were: *Myrsine lessertiana*, *Polyscias hawaiensis*, *Persea americana*, *Artocarpus altilis, Psydrax odorata, Mangifera indica, Rhus sandwicensis, Terminalia catappa, Samanea saman.* For each of these outplanted species three individuals were chosen and re-visited monthly to collect presence/absence data for flowering and fruiting. In the event that an individual that has been chosen for phenology recording dies, we have replaced this individual with the nearest outplant of the same species to continue tracking phenology.

3.7.5 Seed Rain

Seed input is determined by quantifying the amount of seed rain falling into each treatment. We have placed five seed traps (collection area; 0.166 m^2 per trap) in every plot. Seed traps were collected monthly; beginning in January 2014. Each collection was dried at 70ºC for at least 48 hours. The seeds were then sorted from the rest of the sample, identified to species and native/non-native non-invasive versus invasive designation, and weighed.

3.7.6 Native Recruitment

In conjunction with the mapping and measuring of existing trees and outplants, we conducted surveys for seedlings and new recruits that appeared in the plots post-clearing. These seedlings and recruits could either be species of existing native trees or outplants. A plant was considered a seedling if it did not have a DBH $\geq$ 1.0 cm at 1.3 m height, and a recruit if it did have a DBH $\geq$ 1.0 cm at 1.3 m height.) To conduct the seedling census, five transects were run across the length of the plots at increments of 4 m apart, with the first starting at the southwest corner and ending at the northwest corner. At 2 m intervals, all seedlings were identified within a 1 m^2 quadrat. Recruits were tagged, mapped, and measured during the outplant census.

3.7.7 Decomposition Experiment

A decomposition experiment was designed in order to determine species differences in leaf litter decomposition rate as well as treatment differences, when considering the species mix as a whole. In this experiment we were testing three hypothesis: $H_{1;}$ Species differ in their decomposition rates, H_2; Mixed litter from the moderate treatments decomposes faster than from the slow treatments; due to choosing species for the slow treatments that would slow down the rate of C cycling, and H_3; Mixed litter from the complementary treatments decomposes faster than from the redundant treatments; due to choosing species in the complementary treatments whose litter qualities might be stimulatory in terms of more diverse microbes. To test H_1 litter of outplant species (5g; dried at 70°C) was placed in decomposition bags (n=10 per species x two time points) constructed of window screening for all outplanted species and the three dominant existing native species (*Metrosideros polymorpha, Diospyros sandwicensis,* and *Psychotria hawaiiensis*) and then placed into a common site that would remain undisturbed. To test H_2 and H_3 litter of all outplant species within each treatment (5g total; dried at 70°C) was placed in decomposition bags (n=10 per treatment mixture x two time points) and then placed into the same common site. The bags were deployed on August 7th, 2015. After being left undisturbed for

four months the first round of bags were collected, samples dried at 70°C and then weighed, and decomposition rates calculated. In August 2016 the second round of bags will be collected, processed, and decomposition rates/curves calculated.

3.7.8 Person-hour Statistics

We kept track of time dedicated to the experiment at KMR in order to help in calculating costs. Beginning in January 2012, we logged hours for all the people working in the field or lab. The time in and out for each person was noted on log sheets, and activities were classified as: 1) plot establishment and initial survey; 2) clearing; 3) planting; 4) maintenance; 5) data collection; and 6) data processing. We also kept track of time weeding our old plots (an original removal experiment that was a pre-cursor to this experiment).

In order to estimate invasion resistance of the plots, and to test the hypothesis that the two complementary treatments have greater invasion resistance (lower weeding effort), in 2016 we started keeping track of weeding hours and weed species per plot. Combined with the native seedling data described in Section 3.7.5, the measure of invasion resistance will be degree of invasion (DI), a slight modification of the two-part index recommended by Guo and Symstad (2008):

$$DI = person\ hours\ spent\ weeding * \frac{total\ number\ of\ nonnative\ species\ recruiting}{total\ number\ of\ native{+}nonnative\ species\ recruiting}.$$

3.8 Development of a Generalizable Model

While the Liko Nā Pilina project has specific restoration goals, the general approach of designing ecosystems with a set of species chosen to embody certain properties and functions is much broader. Toward that aim, we wanted to develop a computer tool that could help users with species choice in restoration. The Restoring Ecosystem Services Tool (REST) was developed in collaboration with four University of Hawai‘i students, who designed it as a project within their year-long software engineering class, COMP SCI 460 and 461. The four students (Bryson Fung, Pauleen Pante, Rueben Tate, and Anthony Vizzone) designed the entire program with input from our team, presented the program at a workshop in Hilo, and are authors on the REST user guide (Ostertag et al. 2016). In March we had a workshop in Hilo attended by at least 31 people, and an optional field trip to our experiment. In April we had a workshop in Honolulu attended by 28 people. Institutions that were represented at the workshop included US Geological Survey, Pohakuloa Training Area (Army), National Park Service, Mauna Kea Watershed Alliance, Three Mountain Alliance, Office of Mauna Kea Management, UH Hilo, UH Mānoa, Oahu Army Natural Resources Program, Hawai‘i Army National Guard, Division of Forestry and Wildlife, Waimea Valley, and US Fish and Wildlife Service.

In addition, the four students entered the Microsoft Imagine Cup Challenge and they were invited to the national finals in San Francisco, signifying that they were in top 5 in the country in their category (World Citizenship). Although they did not win, they had an invaluable experience at the competition and gained many new contacts and skills on how to improve the program. In addition, we have been invited to put on a pavilion on species choice in restoration, using this tool, for the upcoming International Union for the Conservation of Nature conference in Honolulu in Sep 2015.

REST was constructed using Microsoft's Visual Studio 2015 Windows Forms platform. The main program is comprised of three parts: Graphical User Interface (GUI), Database, and Analysis. The GUI was created exclusively with tools found in the Windows Forms resources. The database itself is hosted on a private website implemented using PHPmyAdmin, updated periodically as new data becomes available. The analysis portion includes all algorithms and functions hidden from the user. Principal component analysis (PCA) output graphs are generated using the Accord.Net open source framework. At this time, REST is optimized for Windows-based operating systems only (other platforms may be available in the future).

The tool does not give specific answers, but rather is meant to guide users who approach a restoration problem with specific restoration objectives and species in mind. The tool requires that the user identify a set of candidate species. Data on those species' functional traits are required; these data may be in the program if available from global databases (e.g., Jepson Flora Project 2006, Kattge et al. 2011, Paula & Pausas 2013, USDA NCRS 2016) or can be included by the user. The program provides a multivariate analysis of the species' data, providing the user with a handy visual of the relationships of the species to each other. This visual − a diagram of species in trait space − can then help the user chose species based on the user's needs. REST will not make any decisions, as those are left up to the user, but can be reset with different combinations of species to serve as an iterative tool that aids in decision making.

3.9 Quantifying Ecosystem Services

Ecosystem services evaluated include potential extracted biomass, on-site carbon storage, and estimated biodiversity values. Values include summed aboveground biomass totals for individual on-site woody species. Individuals were either existing prior to treatment (i.e., native), new recruits originating during the study, and the outplants. Valuation excludes carbon stored in belowground biomass, herbaceous species in general, and biomass removed prior to project establishment as well as that removed as a result of ongoing establishment maintenance. Biomass calculations originate from diameter at breast-height sampling events between October 2015 and January 2016. Biomass equations originate from general wet forest species metrics as developed by Chave and colleagues (2009), individual species equations (Asner et al. 2011), or newly-developed equations (Celine Jennison unpub. data). Wood density, diameter, and height data were used to develop new biomass equations (Chave et al. 2009; Zanne et al. 2009; Asner et al. 2011). Calculations include all stems ≥2 cm dbh, but exclude secondary growth such as branches below breast height. To evaluate extracted carbon, we used three measures of site-based biomass removal: selected sawn logs intended for intact uses such as construction; wood chips for plywood and other composites; and wood pulp for the paper industry (RISI 2015). Potential carbon payments for experimental treatment and reference conditions were estimated from similar developed wet tropical forests in Australia (Crossman et al. 2011). Values ranged from $45 per metric tonne of stored carbon to a $10 minimum for land values. Adjusted for currency conversion and inflation, these figures are similar to private/public bid values on California exchanges (TNC 2016).

Biodiversity calculations stem from Curtis (2004) as described in *The Economics of Ecosystems and Biodiversity* database (*TEEB*; Van der Ploeg and de Groot 2010). This evaluation regards Australian tropical wet forest, an ecosystem type with similar human pressures, threats to endemic species, and Western socio-economic context. While generally appropriate, biodiversity

values are based on forested area alone; they do not account for changes in management conditions, species composition, or species origins therein. Thus when applied in our hybrid restoration experiment, *TEEB* calculation parameters encompass all species types ranging from endemics to targeted invasives. In response, we developed a more nuanced methodology to contrast species origins in otherwise similarly-valued experimental and reference plots. In addition to raw values, species biomass was classified as native species endemic to Hawaiʻi alone, native species whose range includes Hawaiʻi and elsewhere (indigenous), non-native species of Polynesian origin, non-native species introduced after Western contact, and invasive non-native species (Daehler et al. 2004). Endemic and indigenous species values (weighting factors of 1.25 and 1, respectively) indicate their worth to preserving Hawaiian ecosystems, with the former further emphasizing the unique genetic contribution beyond species found elsewhere. In contrast, decreased valuation of Polynesian, post-Western, and invasive species (0.75, 0.5, and 0.25, respectively) accounts for cultural, utilitarian, and land cover characteristics of species in question. Multiplying biomass values by weighted factors allows for a more realistic portrayal of their bio-cultural worth to Hawaiian forests.

In previous estimates, approximately 40 person / hours of labor would be required to restore and maintain a single square meter of lowland wet forest at KMR as all native and without any outplanting (after Ostertag et al. 2009). Averaging labor rates for site volunteers through salaried workers at $10 per hour (State of Hawaiʻi 2016), labor required passively restore experimental parcels totals some $640,000. Equating to $4 million per hectare, all-native restoration is well beyond most budgetary constraints at the landscape level. Functional traits-based approaches may present an alternative that more efficiently delivers certain desired ecosystem services associated with an all-native restoration. Materials required for establishing restoration projects vary based on site conditions, necessary equipment, and local product availability. These can include hand and power tools, safety gear, and planting essentials as well as chemical inputs, maintenance and repairs, and any other needs for facilitating ecosystem recovery as plants mature. This analysis includes all site establishment labor and materials necessary for enacting our hybrid restoration project, inclusive of preparation. Values were calculated for the study plot level and scaled to per hectare levels for ease of comparison. As restoration projects often require labor investments beyond allotted timeframes, even when adjusted to site or experimental conditions, additional effort is often required to accomplish project goals. However, this analysis concerns material and labor costs required to enact and maintain hybrid restoration only; experimental and other data collection measurements were omitted from this study. Further, site labor is expected to decrease over time due to species interactions, i.e., upcoming canopy closure and forest maturity. As such, this analysis also includes projected maintenance requirements for 100%, 75%, 50%, and 25% of current rates on a 50-year timeframe. All monetary values were converted using current currency exchanges and adjusted for inflation (OANDA 2016).

During the 2016 IPR, we were asked to justify the inclusion of the return on investment calculation, discuss the methodology and its robustness to changing inputs. Return on investment calculations were chosen because the restoration is not yet profitable (see Table 11), because the outplants are at small sizes and have not yet accumulated much carbon. Therefore we chose to think about the project over a 50-year time window. The return on investment calculations are sensitive to data used; however, we have made calculations under different scenarios. Specifically, we have compared return on investments potential remaining labor investments at

100%, 75%, 50%, and 25% of current rates on a 50-year management timeframe. Returns also include high and low market values.

4. Results and Discussion

4.1 Functional Trait Profiles of Lowland Wet Forest Species in East Hawai‘i

The trait values used for the principal component analysis to determine the experimental treatments (native and exotic species) are shown in Table 5.

Table 5. *List of native and exotic species and their trait values. From this list of species, a subset where chosen for the four experimental treatments, based on principal component analysis (PCA). Species codes are in Table 3.*

Species code	Leaf to petiole ratio	Leaf thickness (mm)	Leaf area (cm^2)	Leaf water content (%)	LMA (g/m^2)	%N	%C	C:N	%P	Broad to shade ratio	Max. altitude range (m)	Water-use effici-ency	Max. plant height (m)	Seed mass (g)	Archit-ecture	Stature	Stem specific gravity (g/cm^3)
ALMO	2.05	0.22	98.70	48.22	0.009	1.95	43.08	22.88	0.18	2	1200	60.37	20	8.99	2	2.9	0.31
ANPL	19.91	0.33	55.28	49.51	0.012	1.32	39.26	30.27	0.08	1	914	54.84	12	0.04	2	2.0	0.42
ARAL	10.39	0.34	781.49	57.64	0.011	2.34	38.95	16.99	0.19	3	1551	97.66	15.5	5.89	1.97	2.8	0.29
BRPA	2.63	0.46	176.83	67.69	0.007	2.54	37.52	14.89	0.30	0.66	1500	61.72	12	0	1.18	3.0	0.40
CAIN	9.19	0.39	88.88	54.03	0.017	1.08	46.34	43.12	0.09	2	800	115.45	20	6.66	1.9	3.0	0.44
CIGL	1000	0.38	3500	33.65	0.014	1.34	46.89	36.96	0.08	0.66	1829	98.68	5	0.00	3	2.0	0.21
CIME	1000	0.33	3500	59.62	0.009	1.38	44.32	33.14	0.09	0.66	1829	98.68	10	0.00	3	2.0	0.21
CONU	1000	0.40	3500	60.55	0.015	1.03	46.43	45.99	0.11	0.33	600	126.78	21.5	576	3	3.0	0.63
COSU	3.72	0.27	107.80	70.42	0.009	2.10	40.29	20.20	0.23	1	150	59.39	15	1.66	2	3.0	0.50
DISA	13.84	0.35	9.41	23.00	0.018	1.03	44.33	43.69	0.06	2	1200	51.44	12	0.19	2.04	2.7	0.62
MAIN	7.26	0.21	99.18	42.65	0.016	1.24	42.51	35.05	0.07	3	1200	64.09	40	16.5	2.08	2.6	0.42
MEPO	9.62	0.39	10.42	34.82	0.020	0.81	46.98	59.14	0.05	1	2600	116.01	24	0.01	1.90	2.8	0.55
MESP	8.26	0.44	52.76	59.98	0.014	1.21	43.97	36.48	0.06	1	1200	108.25	12	0.01	2	2.0	0.41
MOCI	16.83	0.21	307.74	79.62	0.006	2.43	39.74	17.07	0.16	1	800	96.60	10	0.01	2.66	1.8	0.32
MYLE	43.62	0.30	35.83	62.76	0.009	1.01	39.74	39.96	0.05	0.50	1219	61.60	18	0.04	2.58	2.0	0.43
PATE	1000	0.70	3500	63.55	0.025	1.01	44.18	47.71	0.06	3	610	106.53	20	0.61	2.74	2.3	0.50
PEAM	7.72	0.21	127.09	50.47	0.008	1.57	46.06	31.94	0.07	3	490	98.06	20	15.30	1.88	2.1	0.38
PIAL	3.98	0.24	46.45	57.22	0.006	1.72	35.30	21.21	0.12	2	2400	42.26	9	0.00	1.62	1.9	0.35
PLUM	6.70	0.33	113.26	79.13	0.009	2.42	41.94	17.77	0.31	1.5	2000	122.39	5	0.03	2	1.8	0.14
POHA	27.67	0.38	51.91	73.76	0.010	1.39	44.84	33.22	0.13	1	800	149.04	25	0.01	2.00	3.0	0.35
PRBE	1000	0.41	3500	58.20	0.018	0.82	43.83	53.66	0.10	0.33	1200	141.58	30	2.50	3.00	3.0	0.50
PSHA	6.57	0.34	58.52	68.48	0.010	1.21	42.87	36.08	0.05	1	1524	71.89	12	0.08	2.27	2.0	0.36
PSOD	20.43	0.27	13.72	46.04	0.015	1.39	46.25	35.19	0.09	1	1100	69.91	10	0.09	1.63	2.3	0.59
RHSA	26.64	0.30	40.09	46.57	0.012	1.47	45.67	32.70	0.11	1.5	6190	75.65	8	0.01	1.84	2.6	0.54
SASA	5.09	0.28	5.21	52.21	0.010	3.20	48.50	15.32	0.12	1.5	1100	63.66	35	0.17	2	3.0	0.45
SYMA	14.57	0.41	91.84	64.05	0.015	1.37	43.76	33.50	0.18	2	1200	75.31	25	3.00	2	3.0	0.39
TECA	23.63	0.23	263.35	65.72	0.008	2.14	41.60	19.98	0.23	1.5	1200	75.44	40	2.47	2.16	2.6	0.41
THPO	2.50	0.22	158.47	70.82	0.005	2.86	42.04	15.05	0.29	2	150	112.31	10	0.15	1.73	2.6	0.41

Native and exotic species grouped separately from each other in trait space. Natives tended to have higher values of foliar C:N and leaf mass per area, and smaller values for foliar N, seed mass, leaf area, and maximum height (Figure 8b). The first axis of the PCA explained 38% of the variance and Axis 2 explained another 16%. Surprisingly, invasive species overlapped with both native and exotic species, rather than occupying a distinct area of the PCA (Figure 8a). Overall the PCA for all 47 species explained approximated 49% of the variance, with Axes 1 and 2 accounting for 31% and 17%, respectively. Like Figure x, species along the first axis are best separated by leaf C:N, N, and LMA, but along the second axes the most important trait variable are slightly different, and are leaf area, leaf water content, and maximum height.

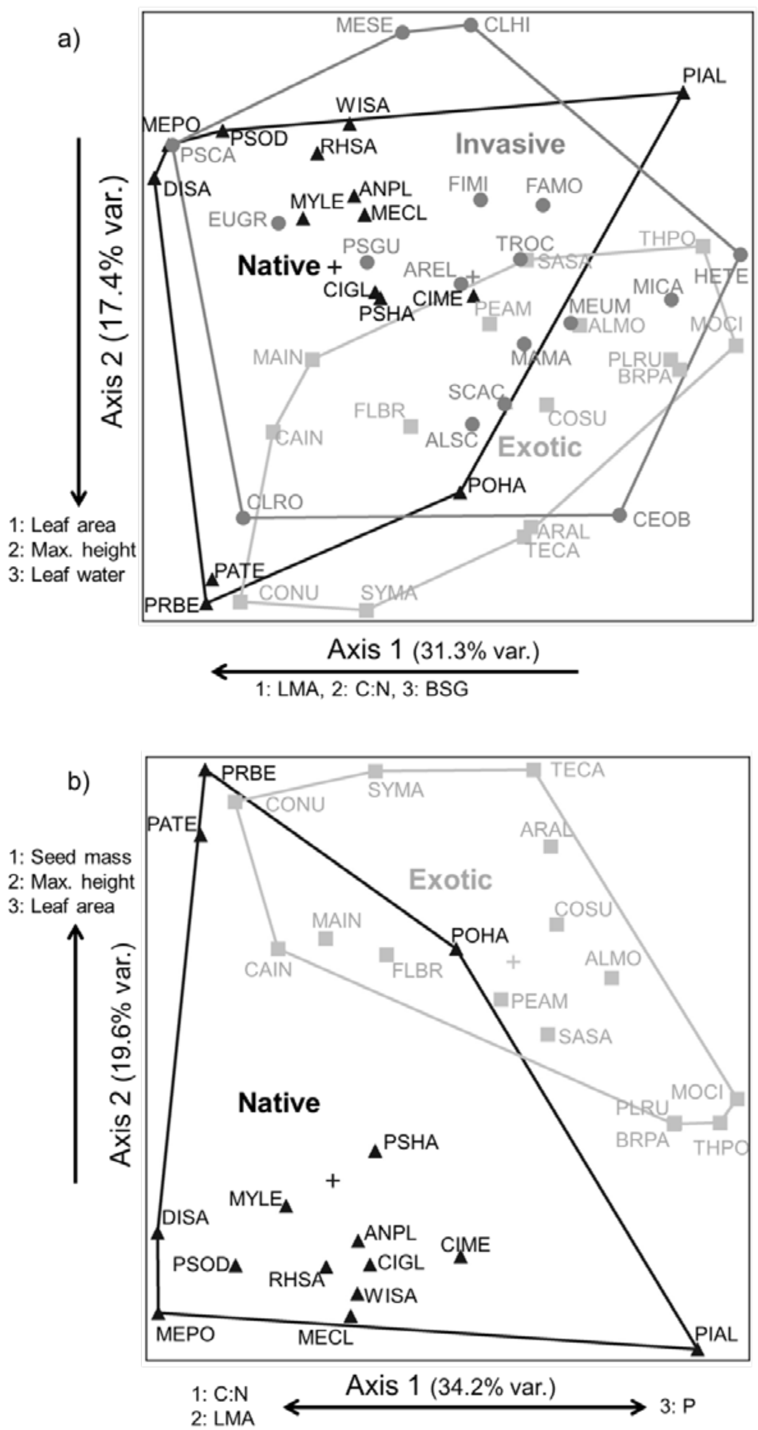


Figure 8. *Principal components analysis of native and exotic species used to justify the mixing of native and exotic species in restoration treatments; .**a)** PCA result for all 47 species, which cumulatively accounts for 48.8% of the variance. Axis 1 explains 31.3% of the variance while axis 2 captures 17.4% of the variance. **b)** PCA including only native and exotic species, which accounts for 53.9% of the variance. Axis 1 captures 34.2% of the variance, and axis 2 captures 19.6% of the variance. In both figures the black triangles represent native species, light gray squares represent exotic species and dark gray circles represent invasive species. Convex hulls are drawn, enclosing all points in a group. Species abbreviations are in Table 3.*

There are several important points to note when comparing these two PCA graphs in Figure 8. First, the clear separation between the majority of the native and exotic justifies the original objectives and hypothesis of this project. A forest comprised of a mixture of both native and exotic species will present greater functional trait complementarity than that of a forest comprised by either type of species alone. Given the rates of native plant species extirpation on the islands, the functional diversity of the current suite of native species probably differs from its historical precedents. While it is impossible to assess the functional trait overlap between extant and extinct species these forests, it is clear that the present functional diversity of native species is limited. Thus, although non-native species may not exactly replace extinct natives, the result of including non-natives is clearly a forest with higher functional diversity. We hypothesize that this higher functional diversity will be advantageous in the goals of higher carbon sequestration and higher resistance to weed invasion, which should lead to a lower understory cover that fosters native regeneration and allows for the greater human mobility required for military training.

Second, the invasive species do not occupy a unique area of trait space but tend to overlap with the native and exotic species. In other words, native and exotic species tend to differ functionally, but invasives, as a group, overlap with both of them. Our findings are generally consistent with meta-analyses that find similarities between natives and invasives (e.g., Leffler et al. 2014, Ordonez 2014), and support the hypothesis that some invasive species are successful in Hawaiian forests because they are similar to the natives. However our results also imply that invasive species are successful in HLWF because they have a broad range of functional strategies which allow them to outcompete both native and exotic species. A potential pitfall of functional trait studies is that not all ecologically relevant 22 characteristics or dimensions may have been accounted for explicitly in our choice of measured traits. It is likely that traits, such as faster relative growth rates, which were not explicitly captured in our analyses (although stem height and density can serve as proxies, Ordonez 2014), can offer an advantage to some introduced species.

The differences between native and non-native species included in our experimental design highlight the principles of ecological redundancy and complementarity. That is, species in a community with high redundancy will be more similar in trait space, while a community with higher complementarity will encompass greater functional diversity. Either type of community may effectively provide a desired environmental service, such as carbon sequestration. However, theory predicts that a more complementary forest assembly would have greater ecological stability, including both resistance to invasion and ability to withstand changing environmental conditions. These are important properties to consider in restoration and management, especially in the case of tropical islands such as the Hawaiian archipelago that have high rates of biological invasion and high vulnerability to global climate change.

In addition to the analysis grouping species by geographic origin we also examined the native plants in more detail. When examined this way, the PCA for native species shows a clear separation between the arborescent species (*Pritchardia*, *Pandanus* and two *Cibotium* tree ferns) and the rest of the species (all of which are true woody species; Figure 9). This separation is primarily based on Axis 2 values (the most important of which include measures of leaf area, leaf:petiole and canopy height), although important traits from Axis 1 also play a role (primarily

LMA, leaf thickness and maximum plant height). Arborescent species separated from each other based on traits which are consistent with evident differences in their growth habits. For example, *Pritchardia*, a palm, is taller and has a denser stem than *Pandanus* or the tree ferns, as well as having much larger seed mass, and these differences are reflected in the PCA.

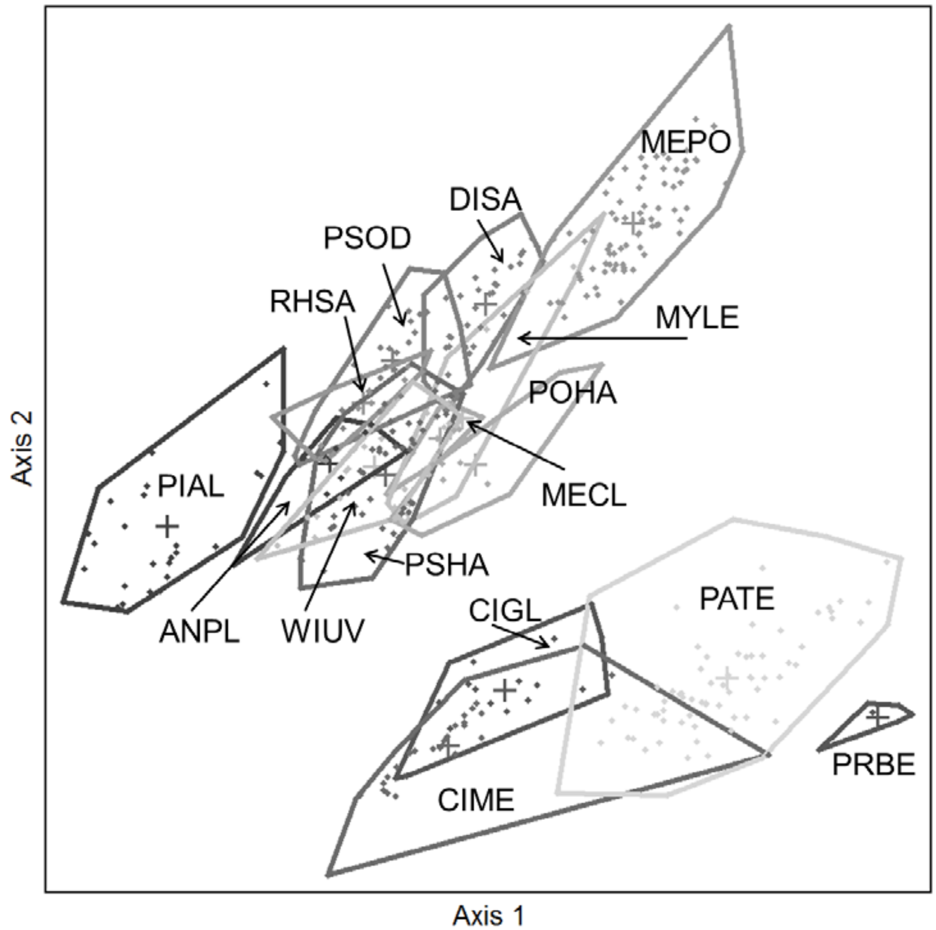


Figure 9. *PCA for all species (55% of the variance explained). Axis 1 (32% of the variance) is mainly defined by measures of leaf thickness, LMA and maximum plant height. Axis 2 (23% of the variance) is mainly defined by measures of leaf area, leaf:petiole and canopy height. Each point represents an individual plant, convex hulls and centroids are shown for each species. The four arborescent species are clustered near the bottom right hand corner of the PCA.*

Due to the nature of our sampling regime, we were unable to carry out analysis to statistically test if either substrate age or rainfall influences a species distribution in trait space and therefore we are unable to reach any conclusions about whether there exists a relationship between rainfall or substrate age and intraspecific variation in the species sampled.

Given the characteristic life-form differences between woody species and arborescent ones, their grouping in trait space and separation in the PCA is not surprising. The similarity among the majority of woody species suggests a great deal of trait overlap among them, and thus favors the hypothesis that remaining native Hawaiian species in this habitat type show trait convergence.

We also examined the two species that were found at many of the sites in order to look at intraspecific variation in functional traits. A PCA on the trait values for *Metrosideros* and *Pandanus* explains 68 percent of the variance between these species (Figure 10) and, not surprisingly, shows a strong separation between the two species on the first PCA axis. This separation is mainly due to water-use efficiency, seed mass and maximum plant height. It is important to note that neither leaf area nor petiole length (which were a single value for all *Pandanus* samples) were taken into account for this PCA. Interestingly, the second PCA axis shows tighter grouping among the 82 *Metrosideros* samples than it does among the 73 *Pandanus* samples. Foliar N, followed by P and C:N are the main traits involved in the scatter of individual plant trait values along Axis 2. Multivariate functional diversity analyses showed that the functional richness (area of trait value occupied, represented graphically by the convex hull containing the individuals within each species) was greater overall for *Pandanus* than for *Metrosideros* (171.04 vs. 104.89 respectively). However the functional dispersion (understood as the distance of all individuals to the centroid or average multivariate species value) in trait space was very similar between species, with 3.32 for *Pandanus* and 3.34 for *Metrosideros*. These results show that there can be variation within a species across different sites, but that intraspecific variation is less than interspecific variation. This result further validates our experimental approach of creating hybrid communities, as there is an implicit assumption in that approach that interspecific variation trumps intraspecific variation.

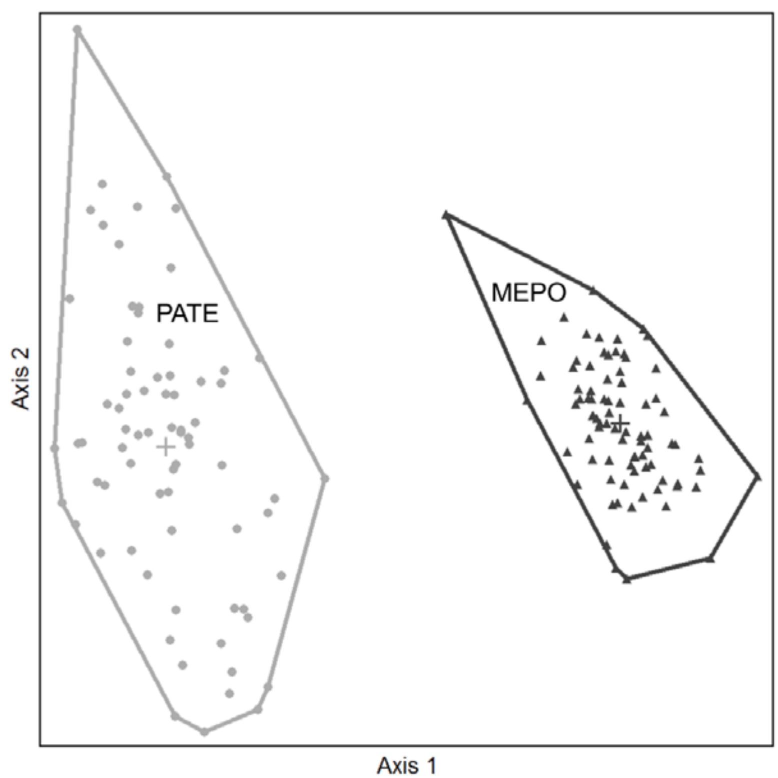


Figure 10. *PCA for all samples of* Metrosideros polymorpha *(clear triangles) and* Pandanus tectorius *(filled triangles). Axis 1 represents 53% of the variance, while Axis 2 captures a further 15 %.*

4.2 Pre-treatment Measurements

The twenty plots were similar in vegetation structure and environmental conditions before the experimental treatments were applied (Table 6, Figure 11). Among the treatments, there was no

significant difference in basal area of native or non-native species, density of native and non-natives, LAI, canopy openness, or soil pH or nutrients (C, N, P, Mg, Ca, Na, K). Although there was no systematic bias relating to treatment, there was considerable variation in the structural variables among the plots. The average native basal area (range 7.5-38.5 m^2/ha) was generally similar but usually smaller than non-native basal area (range 10.3-47.3 m^2/ha). However, non-native stem density (range 12,000-31,500 stems/ha) greatly outnumbered native stem density (225-2350 stems/ha) (Figure 11). Out of eight native species present, three were quite frequent: of stems ≥ 2 cm DBH, the canopy dominants *Metrosideros polymorpha* and *Diospyros sandwicensis* were found in 20 and 17 plots, respectively, and the small midstory tree *Psychotria hawaiiensis* was found in 17 plots (Table 3).

Table 6. *Characteristics of the plots before any clearing occurred of the four experimental treatments. Leaf area index (LAI) and soil pH and nutrients represent the average of four samples per plot.*

Treatment	Block	Plot	Canopy Openness (%)	LAI (m^2 leaf/m^2 ground)	pH	C (%)	N (%)	Total P (mg/g)	Total Mg (ug/g)	Total Ca (ug/g)	Total Na (ug/g)	Total K (ug/g)
Reference	1	1	3.27	6.37	5.83	40.52	1.83	26.2	1468.7	6805.3	277.0	278.0
Reference	2	7	2.6	5.33	5.46	41.29	1.83	26.7	1455.3	6571.9	210.7	292.8
Reference	3	12	5.51	4.46	5.66	40.38	1.90	23.3	1510.2	8407.8	192.3	307.8
Reference	4	19	3.11	5.43	6.72	34.68	1.81	26.2	1777.4	9616.5	135.3	355.4
Slow Redundant	1	2	6.2	4.01	5.93	39.24	1.74	32.8	1198.9	5937.4	163.4	245.5
Slow Redundant	2	6	6.01	5.43	5.59	39.33	1.86	33.1	1539.7	6706.6	189.7	259.2
Slow Redundant	3	15	6.1	4.01	5.71	42.53	1.83	27.9	994.6	6137.4	179.0	291.6
Slow Redundant	4	16	2.42	6.26	5.97	38.01	1.70	24.4	1627.7	8442.5	197.0	325.3
Moderate Redundant	1	3	2.74	5.65	5.65	43.45	1.70	25.5	1568.8	6968.1	324.6	317.5
Moderate Redundant	2	9	2.12	6.29	6.13	36.98	1.84	23.8	1591.7	7635.2	159.6	306.5
Moderate Redundant	3	11	10.62	5.47	5.2	38.20	2.00	24.2	1045.9	5782.6	155.2	322.3
Moderate Redundant	4	18	2.02	6.13	6.39	32.99	1.76	23.3	1361.5	5735.4	112.2	267.8
Slow Complementary	1	4	3.49	7.09	5.4	42.44	1.76	26.1	1357.2	6608.7	236.8	248.8
Slow Complementary	2	8	4.16	6.79	5.28	38.78	2.01	23.8	1286.6	6462.6	171.8	327.7
Slow Complementary	3	13	7.78	3.96	6.08	39.08	1.78	25.3	1512.6	6506.1	159.1	319.6
Slow Complementary	4	17	1.86	6.52	5.92	35.88	1.71	41.2	1473.7	7380.5	142.9	287.4
Moderate Complementary	1	5	4.16	5.23	6.76	43.75	1.65	21.4	1708.7	7617.9	276.2	244.1
Moderate Complementary	2	10	2.05	6.09	6.12	41.67	1.93	28.1	1382.8	7520.2	201.8	298.0
Moderate Complementary	3	14	3.13	3.19	5.48	37.58	1.80	20.7	1624.9	8020.5	171.0	313.3
Moderate Complementary	4	20	2.62	6.48	6.17	37.42	1.92	24.1	1162.6	6337.7	170.5	242.2

While treatment plots did not differ significantly before clearing, there were significant block effects in pre-removal native species density ($F_{3,12}$ = 10.390, p = 0.001), canopy openness ($F_{3,12}$ = 4.926, p = 0.018), LAI ($F_{3,12}$ = 6.788, p = 0.006), soil C ($F_{3,12}$ = 7.544, p = 0.004), and soil Na ($F_{3,12}$ = 6.456, p = 0.007). Block 1 had the highest native tree density, soil C and Na, and Block 3 had the highest canopy openness and lowest LAI.

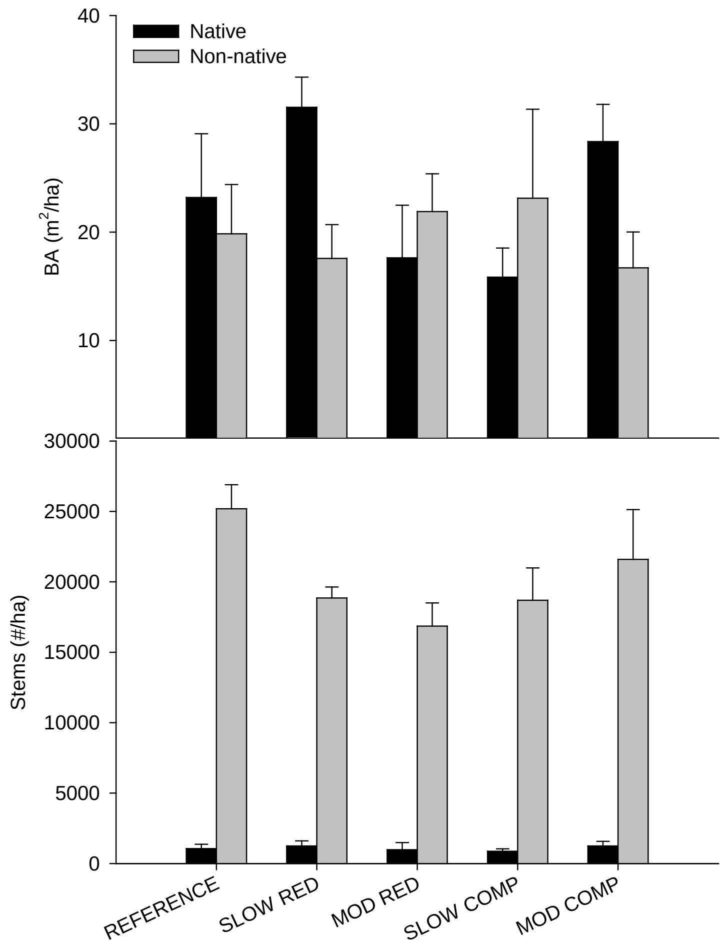


Figure 11*. Basal area and stem density of the plots before the clearing and planting treatments were applied. Before treatment, the plots were similar in native basal area and density, and non-native basal area and density. Values are means + SE, n = 4. In all the following graphs, Reference is the invaded forest plots, Slow Red = Slow Redundant, Mod Red = Moderate Redundant, Slow Comp = Slow Complementary, and Mod Comp = Moderate Complementary.*

4.3 Light Availability

4.3.1 LAI and Canopy Openness

The dominant canopy tree, *Metrosideros polymorpha*, has experienced increased mortality over the last three years. Some of this may be due to stress from clearing and/or infection by the *Ceratocystis* fungus (Figure 12). This fungus causes Rapid Ohia Death (ROD) a new disease discovered recently (Keith et al. 2015). *Metrosideros polymorpha* mortality (%) has been greater in the last two years compared with the 2014 census time point ($F_{(2,20)} = 14.2$, $P < 0.0001$) and for the Moderate Complementary treatment compared with the Reference and Slow Complementary treatment ($F_{4,20} = 4.59$, $P = 0.003$, Figure 12). We speculate that the some of the results being found in the Leaf area index (LAI) and Canopy Openness parameters are due to the *Metrosideros polymorpha* mortality.

LAI was greater in the reference then the treatment plots across all time points ($F_{4,20}$) = 27.84, $P < 0.0001$; Figure 13). Within the reference plots LAI showed a decrease from 2014 to 2015 and

then an increase in 2016 ($F_{4,20}$ = 46.53, P < 0.0001; Figure 13). We speculate that the decrease in LAI was due to mortality in *Metrosideros polymorpha*, and that the increase in LAI was due to fast growing invasives regaining canopy space with their large, broad leaves. Within all treatment plots there does seem to be an increasing trend in LAI from 2015 to 2016, suggesting that the out plants are gradually increasing in canopy breadth. Canopy openness was also greater in the reference then the treatment plots across all time points ($F_{4,20}$ = 15.11, P < 0.0001; Figure 14). Within all treatment plots canopy openness increase from the 2012 pre-removal time point to the 2014-2016 post-removal time points ($F_{4,20}$ = 29.34, P < 0.0001); Figure 14).

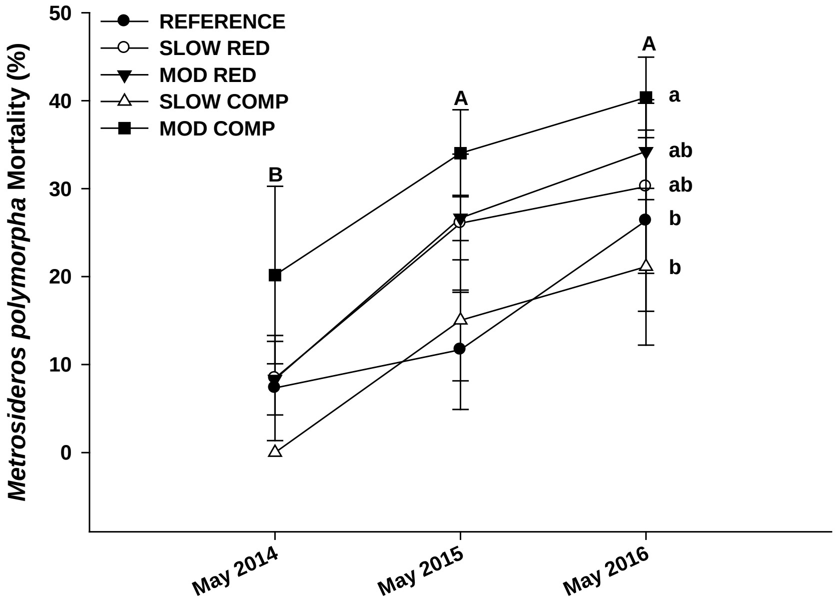


***Figure 12**. Mortality (%) of the dominant canopy tree Metrosideros polymorpha between treatments across three census years (2014-2016). Values are means + SE. Letters that are different represent statistically significant differences across the three time points (upper case) and the five experimental treatments (lower case).*

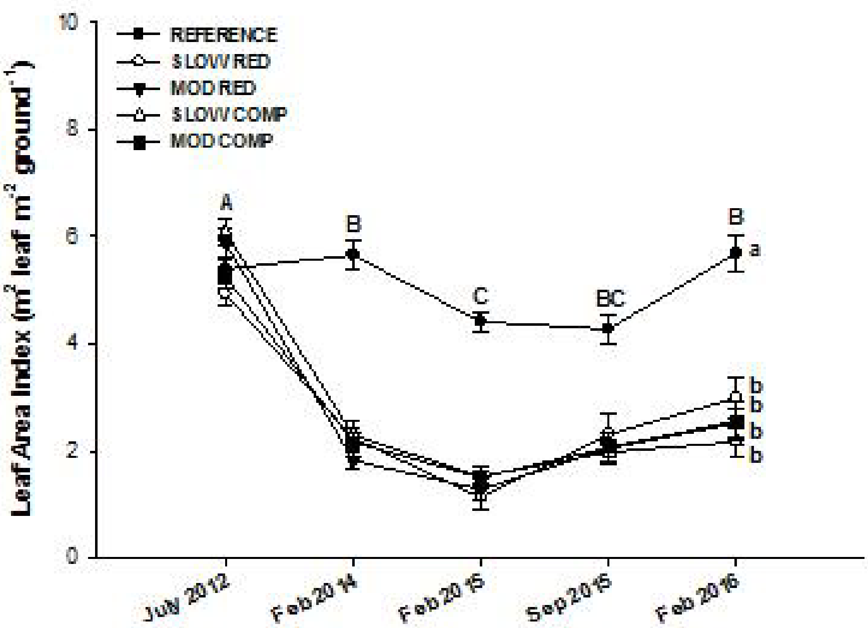


***Figure 13**. Leaf area index (m^2 leaf m^{-2} ground^{-1}) across the treatments for census dates starting with a pre- invasive removal time point in July 2012. Values are means + SE. Letters that are different represent statistically significant differences across the five time points (upper case) and the four experimental treatments (lower case).*

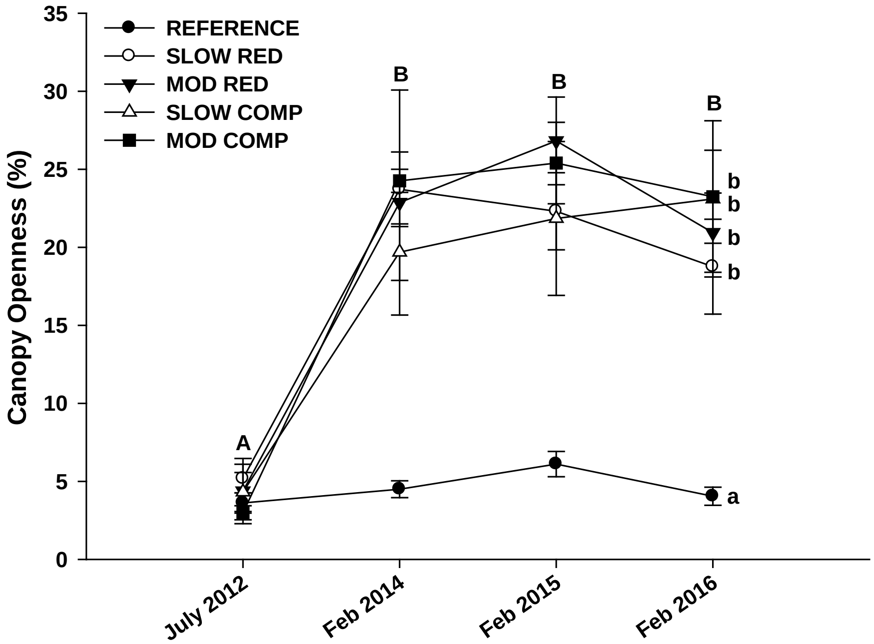


***Figure 14**. Canopy openness (%) across the treatments for census dates starting with a pre- invasive removal time point in July 2012. Values are means ± SE. Letters that are different represent statistically significant differences across the five time points (upper case) and the four experimental treatments (lower case).*

4.3.2 Light Quality

In 2015, the Reference plots had a greater percentage of quadrats surveyed (i.e., microsite %) being characterized by low light than high light quality, due to the nature of the dense invasive canopy (Figure 15). In 2016, the Reference plots had a greater microsite percentage characterized by the medium light quality range, most likely due to mortality in the dominant canopy tree *Metrosideros polymorpha* (Figure 12). In comparison, for both years, the experimental treatment plots had the lowest microsite percentage being characterized by low light quality and the highest microsite percentage of quadrats surveyed being characterized by the high light quality (Figure 15). Large differences have not yet been found between experimental treatments, within light quality categories.

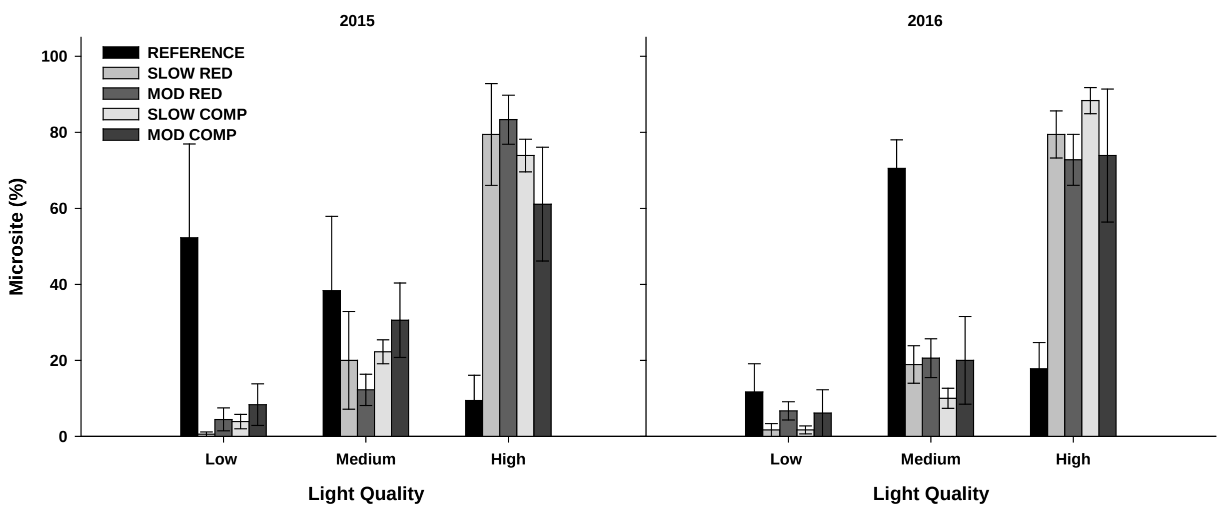


***Figure 15**. Microsites (% of surveyed quadrats) for the reference and experimental treatments characterized by low (R:FR 0-0.4), medium (R:FR 0.41-0.7), and high (R:FR 0.71-1) light qualities in 2015 (left panel) and 2016 (right panel). Values are means ± SE.*

4.4 Litterfall

The total litterfall (g/m^2/y) for both 2014 and 2015 was greater in the reference than treatment plots ($F_{4,20}$ =19.52, P < 0.0001; Figure 16). Across all plots the total litterfall (g/m^2/y) decreased from 2014 to 2015, most likely due to mortality in the dominant canopy tree *Metrosideros polymorpha* (Figure 12).

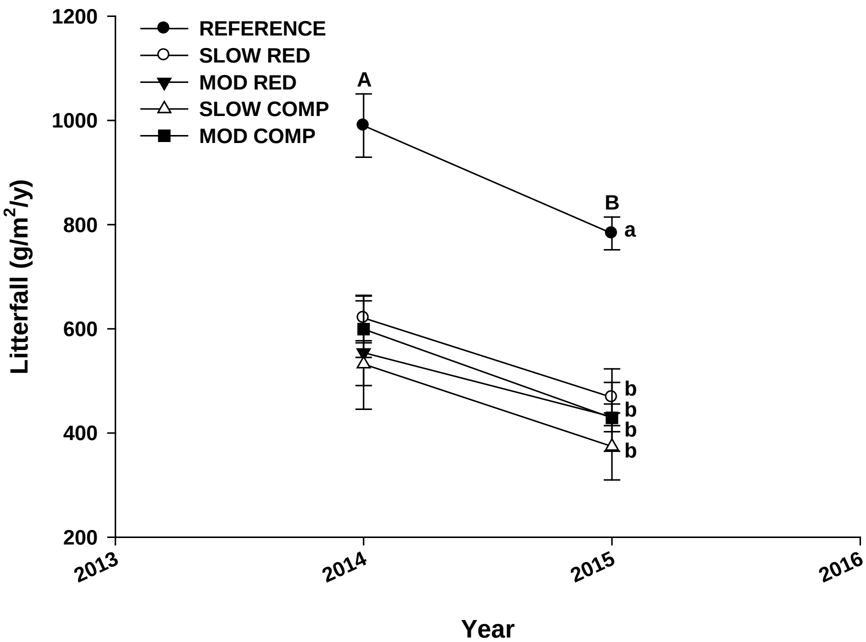


***Figure 16**. Litterfall (g/m2/y) for the Reference and experimental treatment plots in 2014 and 2015. Values are means ± SE. Letters that are different represent statistically significant differences across the two time points (upper case) and the five treatments (lower case).*

4.5 Nutrient Availability

Nitrate, ammonium, and phosphate (ug/mL soln/g resin/day) did not differ between the reference and experimental treatments (Figure 17). Nitrate and ammonium in the experimental treatments showed higher values than phosphate, yet the variability was too large to result in significant differences.

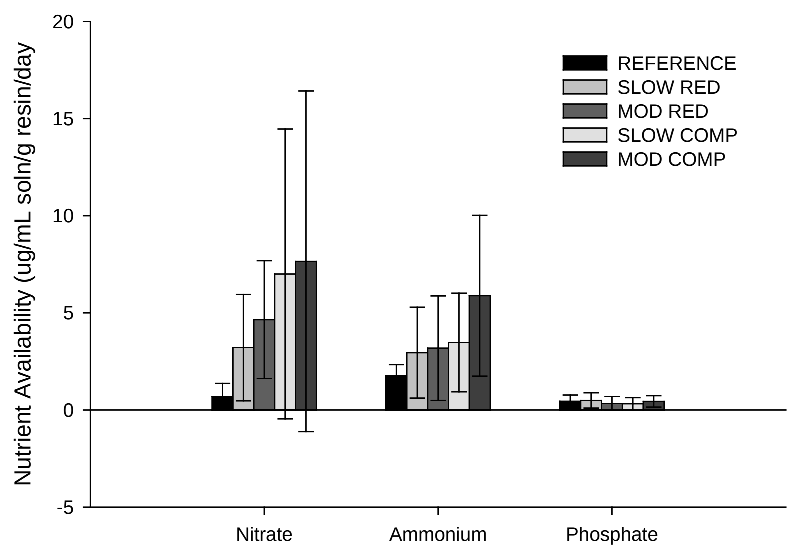


***Figure 17**. Nutrient availability (ug/mL soln/g resin/day), sampled as nitrate, ammonium, and phosphate, for the Reference and experimental treatment plots sampled in 2014. Values are means ± SE.*

The greatest nitrate signals were found from soil sampled in close proximity to *Cocos nucifera*, *Pritchardia beccariana*, and *Rhus sandwicensis* (Figure 18, top panel). Nitrate did not differ significantly within any of the species between the treatments. The greatest ammonium signals were found from soil sampled in close proximity to *Pipturus albidus, Psydrax odorata, Metrosideros polymorpha*, and *Terminalia catappa* (Figure 18, middle panel). Ammonium was significantly greater in the Moderate Complementary experimental treatment for *Myrsine lessertiana*, *Pipturus albidus*, and *Psychotria hawaiiensis*. The greatest phosphate signals were found from soil sampled in close proximity to *Metrosideros polymorpha* and *Pritchardia beccariana* (Figure 18, bottom panel). Phosphate was significantly greater in the Moderate Complementary experimental treatment for *Aleurites moluccana*.

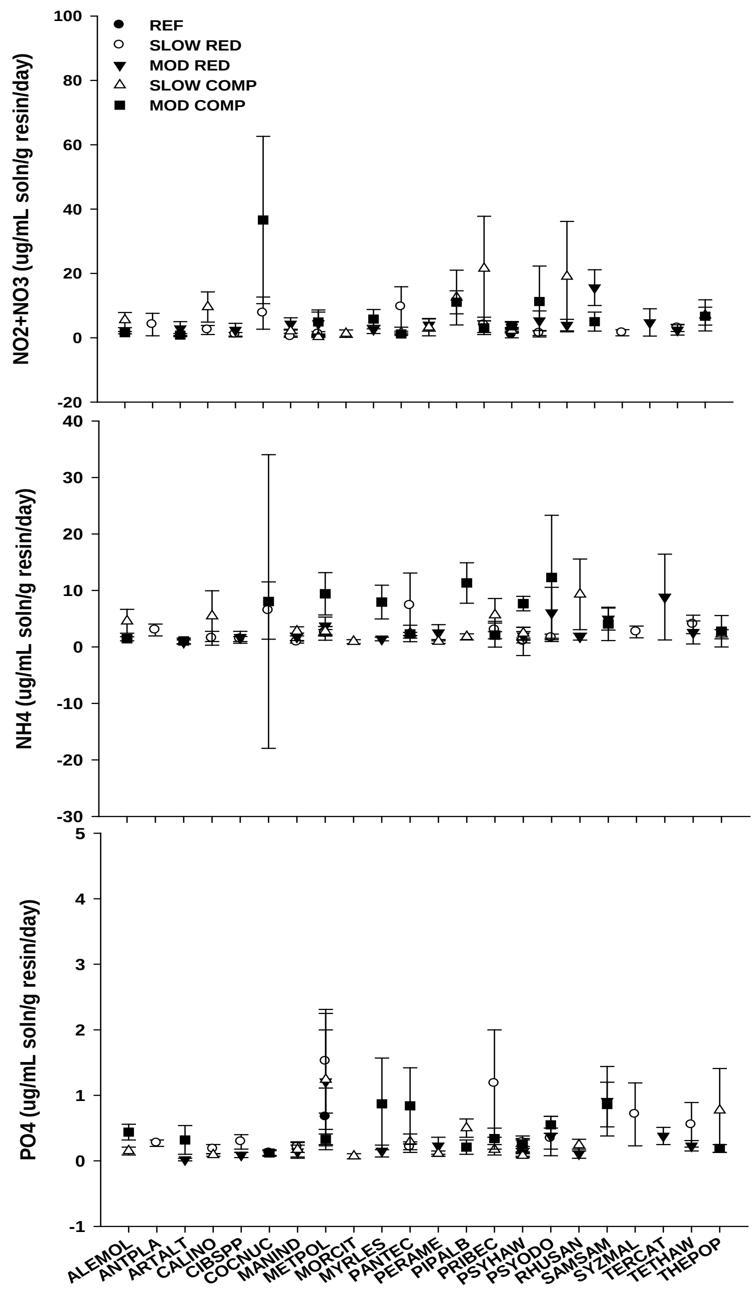


Figure 18. *Nutrient availability (ug/mL soln/g resin/day), sampled as nitrate (top panel), ammonium (middle panel), and phosphate (bottom panel), across the outplant and dominant canopy species, sampled in 2014. Values are means + SE.*

4.6 Species-level Responses

4.6.1 Survivorship and Relative Growth Rates

The outplant survival (%) was greater in the Redundant treatments than the Complementary treatments ($F_{3,16}$ = 14.6, P < 0.0001; Figure 19). Over time the outplant survival (%) has decreased gradually with May '14 > Dec '14 and May'15 > Dec '15 and May'16 ($F_{4,16}$ = 41.7, P < 0.0001; Figure 19). Survival was relatively high (i.e., mean > 70%) across the outplant species for the most recent census (May 201616) (Figure 20). The three species that have experienced low survival rates have been *Antidesma platyphillum* in the Slow Redundant treatment, *Myrsine lessertiana* in the Moderate Redundant and Moderate Complementary treatments, and *Pipturus albidus* in the Slow Complementary and Moderate Complementary treatments (Figure 20).

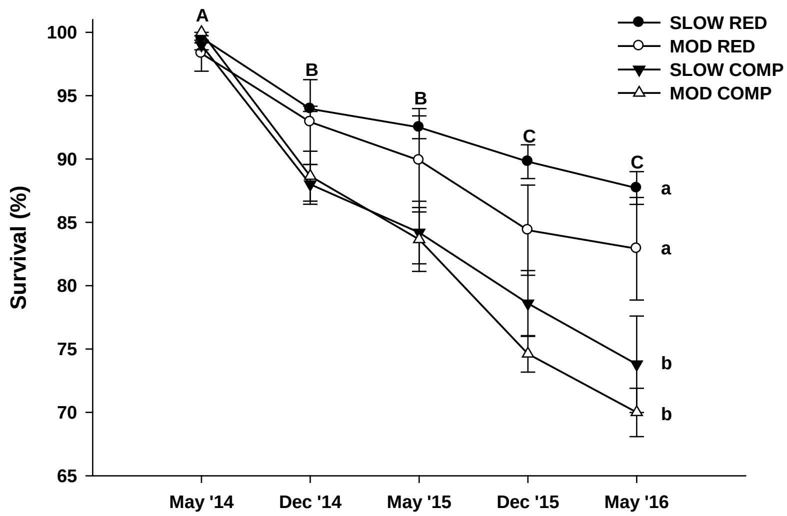


***Figure 19**. Outplant survival (%) across the treatments for census dates since the experimental start in January 2014. Values are means $\pm$ SE. With each figure, letters that are different represent statistically significant differences across the five time points (upper case) and the four experimental treatments (lower case).*

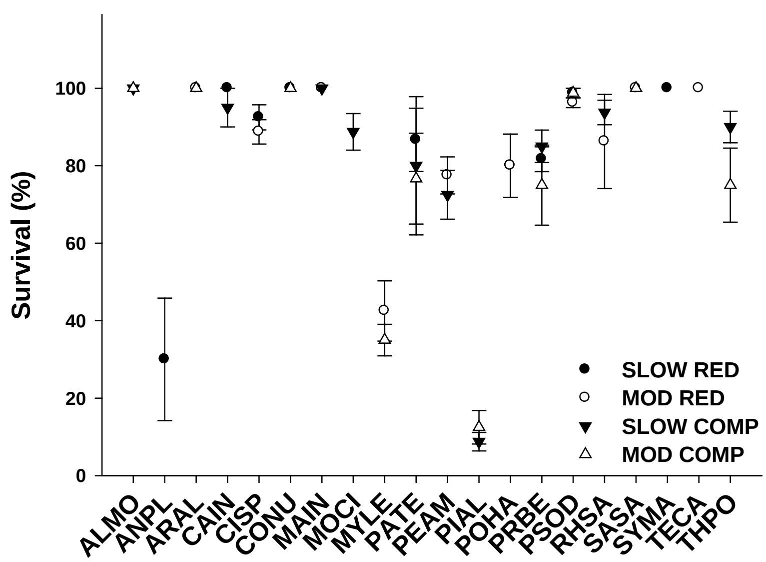


***Figure 20**. May 2016 outplant survival (%) across the species, in the four experimental treatments. Values are means $\pm$ SE.*

The outplant relative growth rates (RGR; % change) steadily decreased across the time points ($F_{3,16}$ = 9.7, P < 0.0001; Figure 21). The treatments did not differ significantly ($F_{3,16}$ = 2.4, P = 0.0768; Figure 20). In the most recent census (May 2016) the species that had the highest RGR (% change) were *Aleurites moluccana*, *Artocarpus altilus*, *Mangifera indica*, *Persea americana*, *Rhus sandwicensis*, and *Terminalia catappa*, all with a mean % change in RGR of 100 or greater (Figure 22). *Antidesma platyphyllum*, *Myrsine lessertiana* and *Pipturus albidus* have all experienced die back resulting in negative growth rate values (Figure 22).

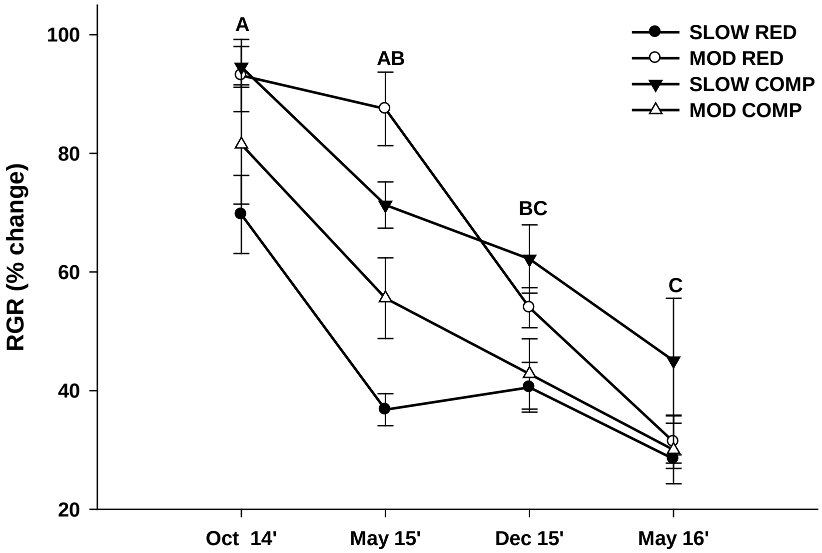


Figure 21*. Outplant relative growth rates (RGR; %) across the treatments for census dates since the experimental start in January 2014. Values are means ± SE. With each figure, letters that are different represent statistically significant differences across the four time points (upper case) and the four experimental treatments (lower case).*

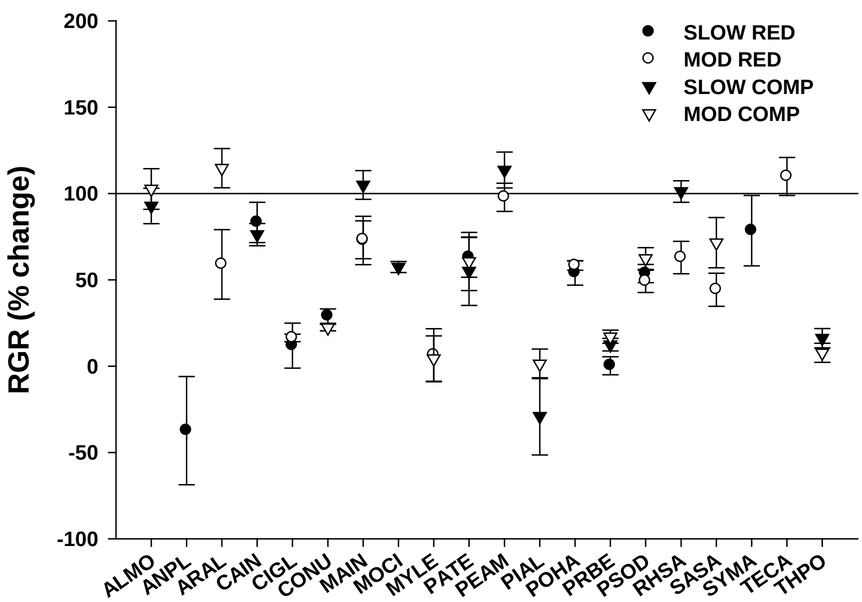


Figure 22*. May 2016 relative growth rates (RGR; % change) across the species, in the four experimental treatments. Values are means ± SE.*

4.6.2 Reproductive Phenology

The number of flowering and fruiting outplant individuals was greatest in the Slow Complementary treatment, followed by the Moderate Complementary treatment, with the lowest number of flowering and fruiting outplant individuals in the Redundant treatments (Figure 23). The greater number of reproductive individuals found for the two Complementary treatments is in direct relation to a greater number of species reaching reproductive maturity.

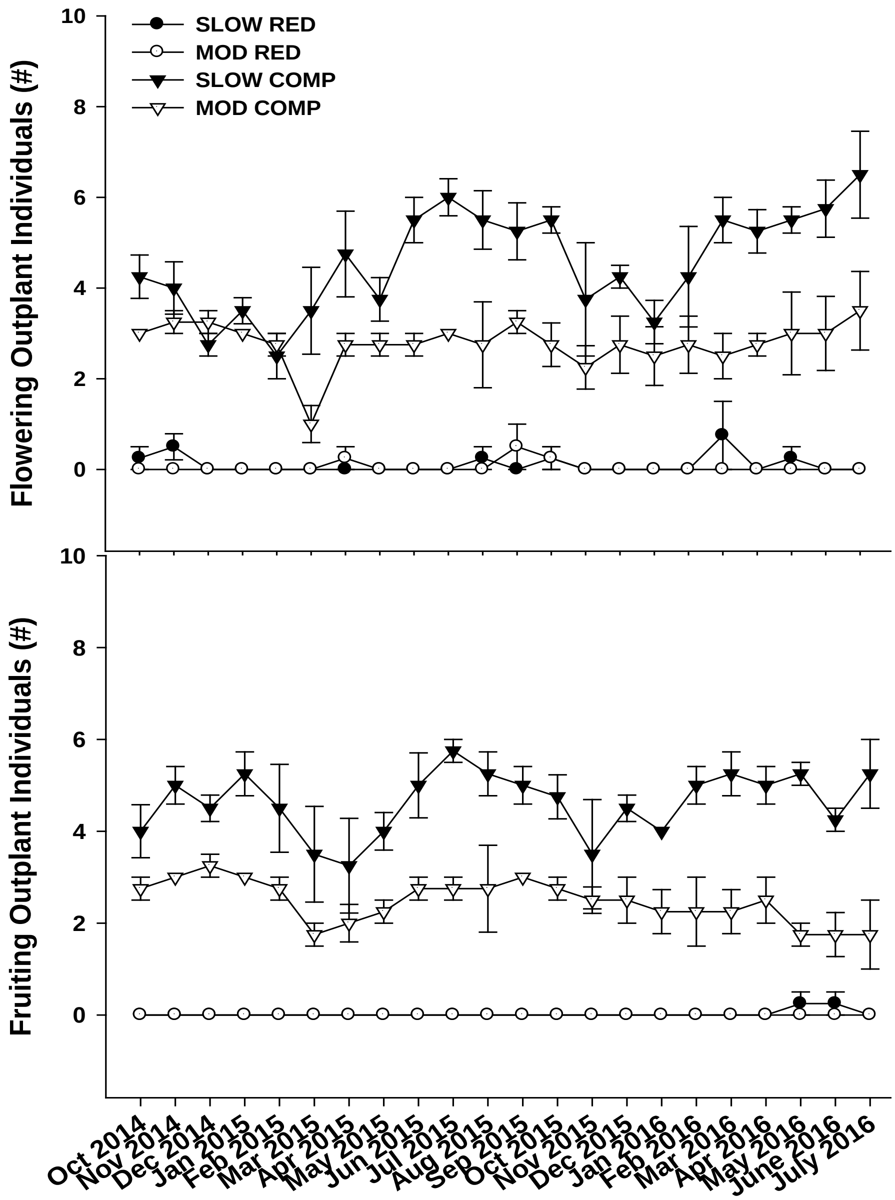


Figure 23. *Flowering outplant individuals (#; top panel) and fruiting outplant individuals (#; bottom panel) recorded monthly from October 2014-July 2016 across the experimental treatments. Values are means $\pm$ SE.*

4.7 Seed Rain

The native seed mass ($g/m^2/y$) was greater in 2014 than 2015 ($F_{1,20} = 7.39$, $P = 0.0102$, Figure 24), most likely due to mortality in the dominant canopy tree *Metrosideros polymorpha* (Figure 5). In 2014, the native seed mass ($g/m^2/y$) was greater in the Slow Redundant treatment than the

Reference ($F_{4,20}$ = 3.69, P = 0.0133, Figure 24). As there was not a significantly greater native basal area or stem density found for this treatment, these results suggest that there was greater reproductive output of the existing natives in the Slow Redundant treatment (Figures 11 and 24). The invasive seed mass ($g/m^2/y$) did not differ between years ($F_{1,20}$ = 2.15, P = 0.1518, Figure 24), yet was significantly greater in the Reference than treatment plots ($F_{4,20}$ = 5.37, P = 0.0018, Figure 24); as the treatment communities have remained clear of large reproductive invasives growing directly in the plots since the initial clearing.

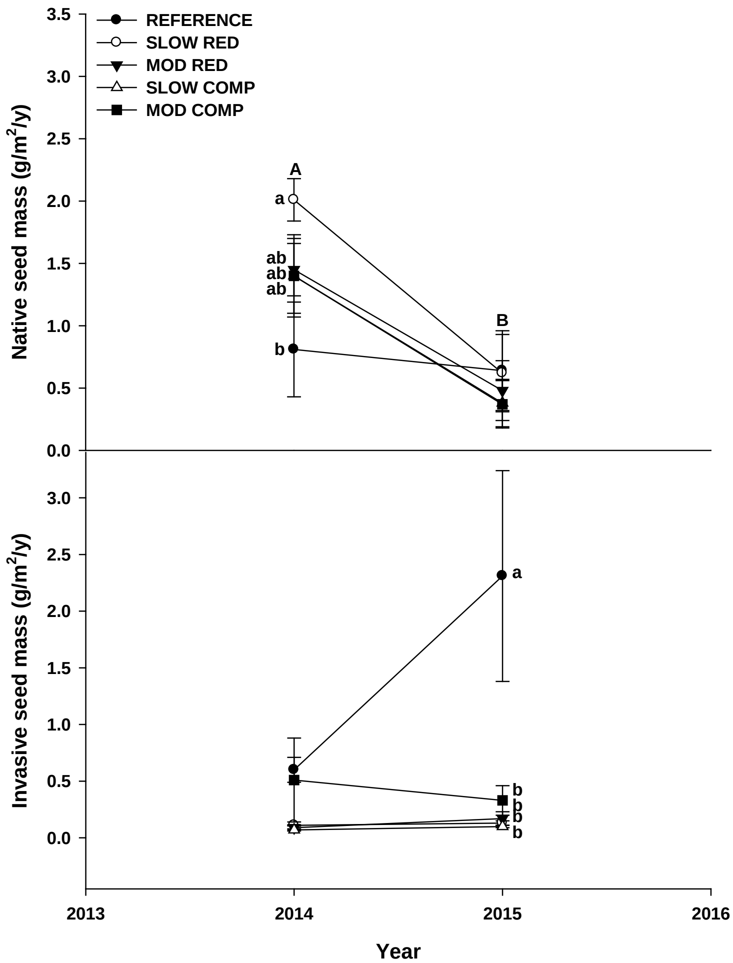


***Figure 24**. Native seed mass ($g/m^2/y$; top panel) and invasive seed mass ($g/m^2/y$; bottom panel) in 2014 and 2015. Values are means ± SE. With each figure, letters that are different represent statistically significant differences across the two time points (upper case) and the five treatments (lower case).*

4.8 Native Recruitment

4.8.1 Native Seedling Recruitment

The native seedling recruitment ($\#/m^2$) was significantly greater in the first survey (May 2014) than the following three surveys ($F_{3,20}$ = 6.85, P < 0.0001; Figure 25). In the first survey (May 2014), the Slow and Moderate Complementary treatments had greater native seedling recruitment ($\#/m^2$) than the Reference ($F_{4,20}$ = 6.28, P = 0.0008; Figure 25). In general, the native seedlings seem to be found in the medium and high light quality environments, although these data are extremely variable (Figure 26).

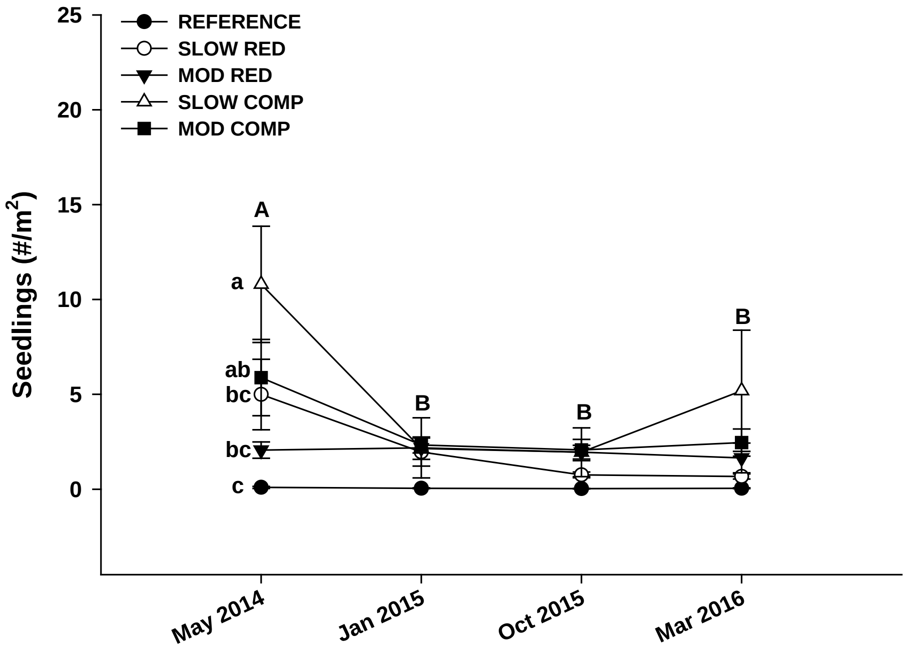


Figure 25*. Native seedling recruitment (#/m^2) for the Reference and experimental treatments. Values are means* $\pm$ *SE. Letters that are different represent statistically significant differences across the four time points (upper case) and the five treatments (lower case).*

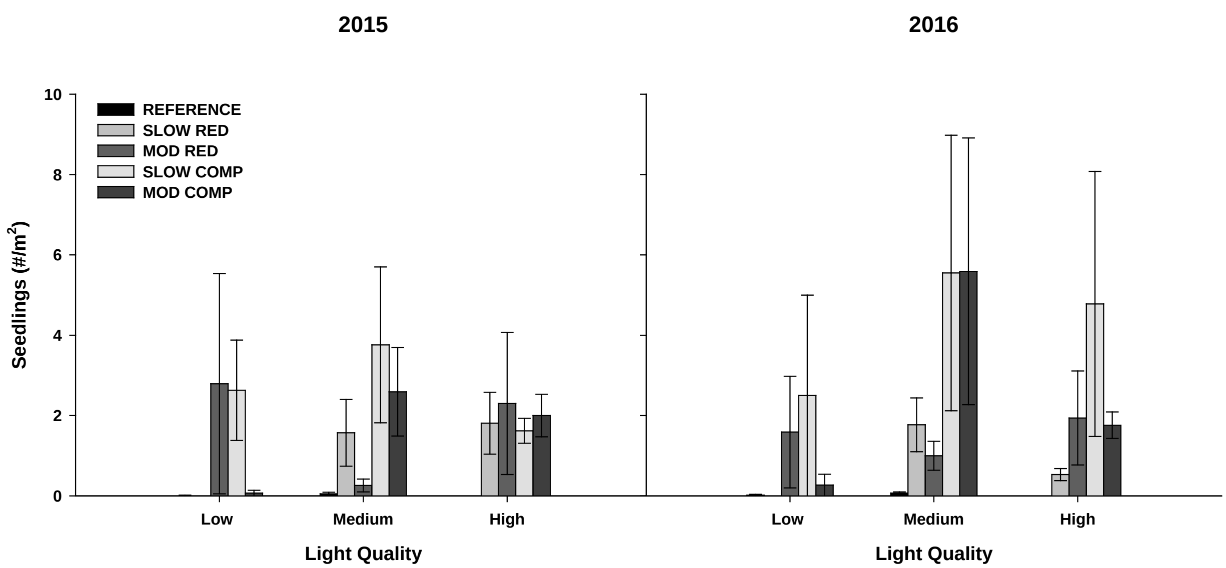


Figure 26*. Native seedling recruitment (#/m^2) across the five treatments found in microsites with low (R:FR 0-0.4), medium (R:FR 0.41-0.7), and high (R:FR 0.71-1) light qualities in 2015 (left panel) and 2016 (right panel). Values are means* $\pm$ *SE.*

4.8.2 Native Sapling Recruitment

Native sapling recruitment (#/m^2) has remained fairly low and constant across the five census dates. Sapling recruitment has not differed significantly across the treatments (Figure 27). There have been slightly higher sapling recruitment rates in the Moderate Complementary treatment, but variation between plots was too high for this difference to be significant (Figure 27).

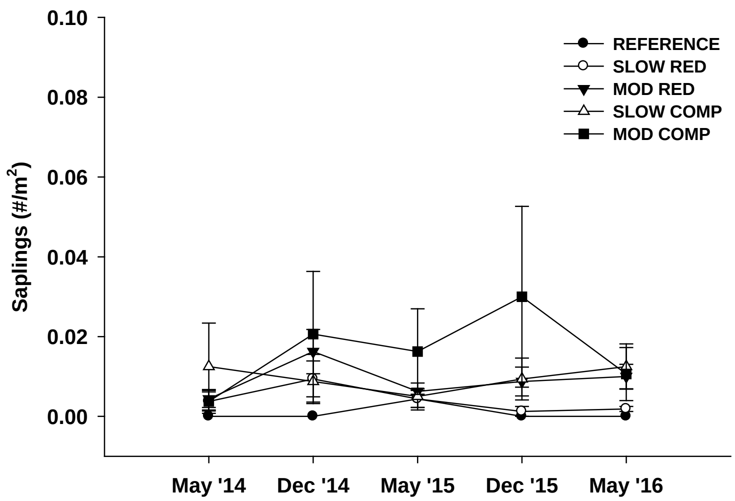


Figure 27*. Native sapling recruitment (#/m²) for the Reference and experimental treatments. Values are means ± SE.*

4.9 Decomposition Experiment

The decomposition rate of leaf material varied widely across the species, *Cibotium glaucum* with the lowest rate (proportion of leaf mass (g) loss = 0.18) and *Morinda citrifolia* with the highest rate (proportion of leaf mass (g) loss = 0.78) (Figure 28). A total of eight species had loss more than half of the leaf material by the four month collection date (Figure 29). The Moderate Complementary treatment had the greatest decomposition rate, followed by the Slow Complementary, Slow Redundant, and Moderate Redundant treatments ($F_{3,40}$ = 15.1, P < 0.0001; Figure 28).

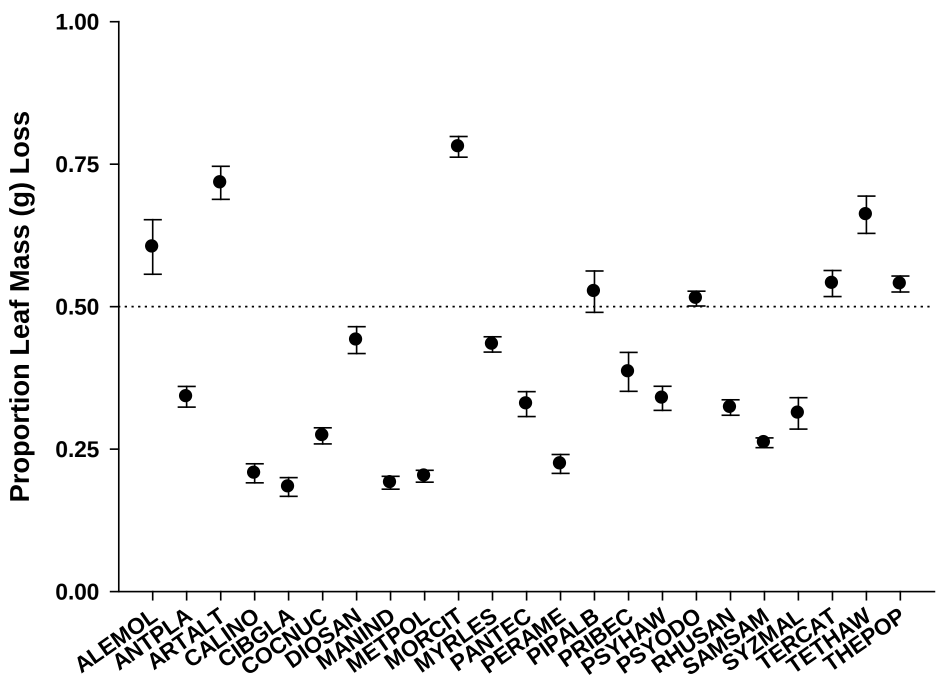


Figure 28*. Decomposition rate (proportion of leaf mass (g) loss) across the 20 outplant and two dominant canopy species calculated at the four month collection time point. Values are means ± SE.*

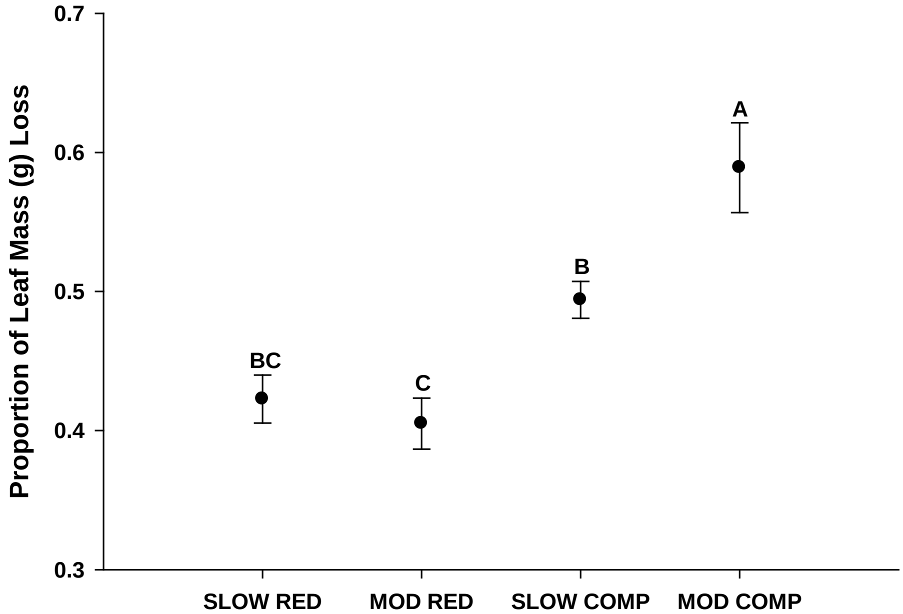


Figure 29. *Decomposition rate (proportion of leaf mass (g) loss) across the four experimental treatments, calculated at the four month collection time point. Values are means ± SE. Letters that are different represent statistically significant differences across the four treatments.*

4.10 Person-hour Statistics

Over the course of the project data and maintenance tasks have been the most time consuming (Figure 30). Clearing of the plots and planting were also significant time investments in the initial phases of the project. Of the present tasks, over half of the time is spent on data collection and processing, and the rest on maintenance.

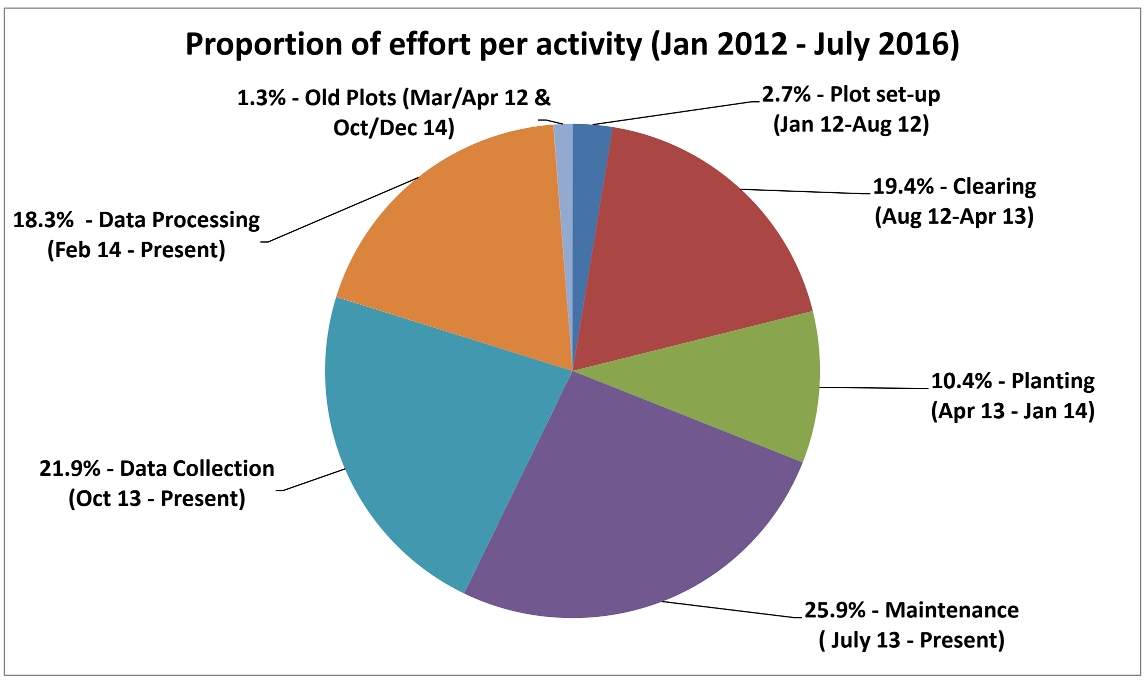


Figure 30. *The proportion of effort, in terms of person-hours per project activity starting in January 2012 through July 2016.*

The person-hours weeding has fluctuated over the course of the project because we weed in spurts, usually with a large group. Initially we weeded every 4 months and later we switched to every 6 months (Figure 31). The effort went done at first, likely because some of the seed bank was exhausted. Later it went back up because of new seed rain. However, as time goes on and the canopy closes we expect to see weeds go down, as we are already noticing weeds decreased under large plants that are creating shade. At present however there is no significant difference in the degree of invasion (Figure 32, $F_{3,8} = 0.15$, $P = 0.926$).

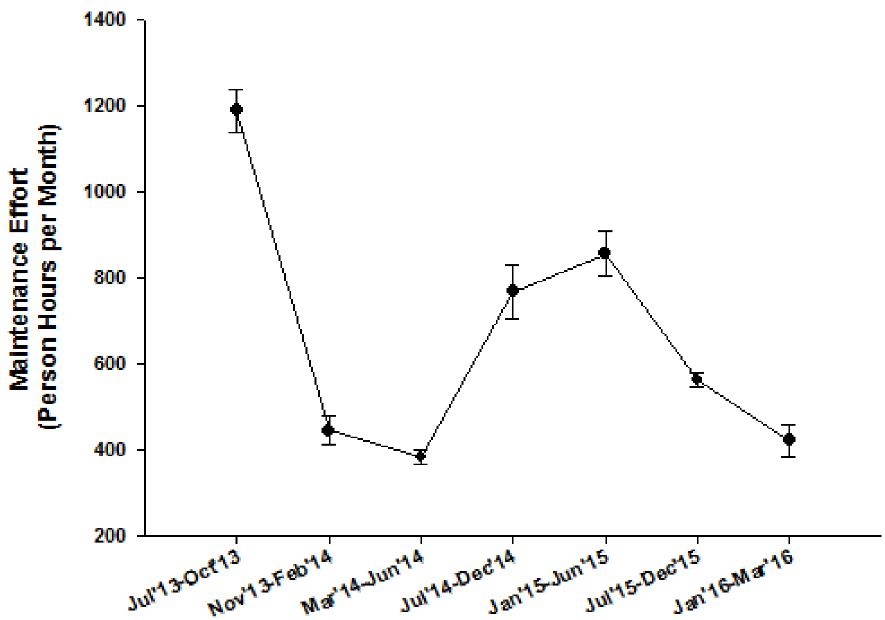


Figure 31. *Person-hours per month weeding. Weeding is conducted in rounds, initially every 4 months and later every 60 months. The fluctuations represent different weeding periods.*

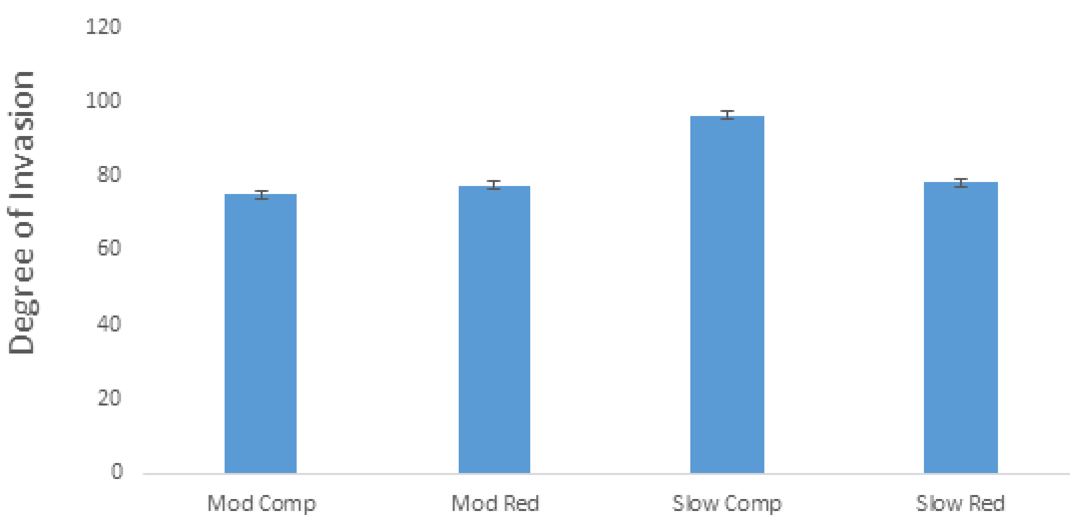


Figure 32. *Degree of invasion across the four treatments. Degree of invasion combines weeding hours, number of weeds, and number of native seedlings. Values are means ± SE.*

4.11 Development of a Generalizable Model

The REST program is now fully functional. The user chooses restoration goals, species and traits (Figure 33) and a PCA is conducted (Figure 34). We are working on linking the program to the PI's website. An important need is that more data should be incorporated into REST to make it more valuable to resource managers.

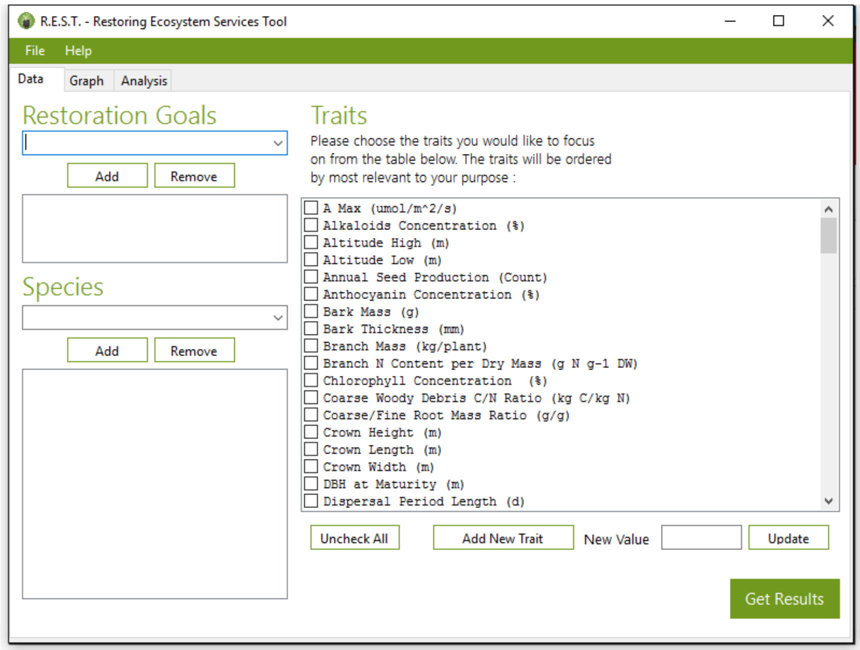
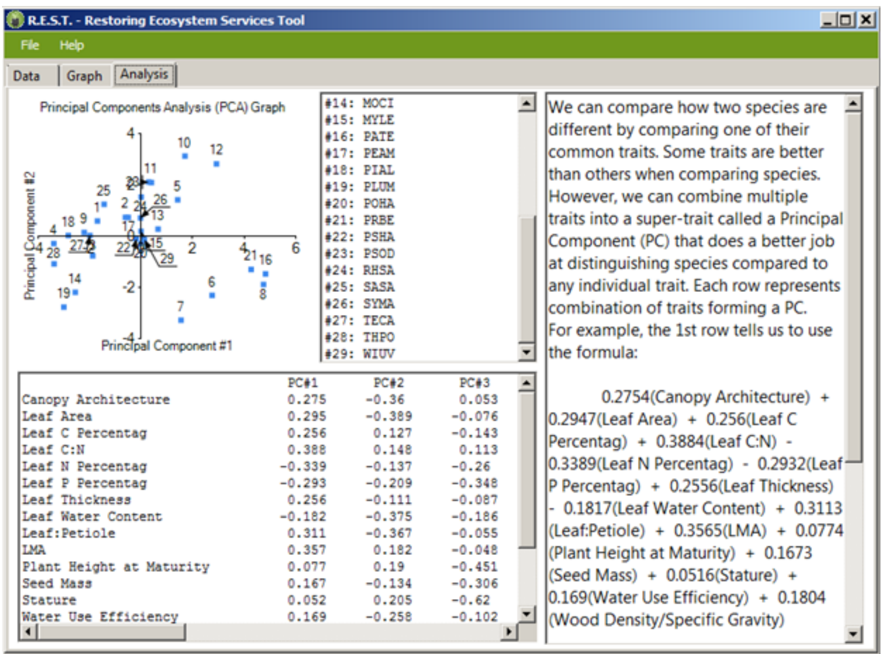


***Figure 33**. Screenshot from REST species selection program. Functional traits of plant species, connected with pre-programmed restoration goals, allow users to determine potential species compositions prior to enactment.*



	PC#1	PC#2	PC#3
Canopy Architecture	0.275	-0.36	0.053
Leaf Area	0.295	-0.389	-0.076
Leaf C Percentag	0.256	0.127	-0.143
Leaf C:N	0.388	0.148	0.113
Leaf N Percentag	-0.339	-0.137	-0.26
Leaf P Percentag	-0.293	-0.209	-0.348
Leaf Thickness	0.256	-0.111	-0.087
Leaf Water Content	-0.182	-0.375	-0.186
Leaf:Petiole	0.311	-0.367	-0.055
LMA	0.357	0.182	-0.048
Plant Height at Maturity	0.077	0.19	-0.451
Seed Mass	0.167	-0.134	-0.306
Stature	0.052	0.205	-0.62
Water Use Efficiency	0.169	-0.258	-0.102

***Figure 34.** Screenshots showing the PCA output from the REST program, using Liko Nā Pilina data as an example.*

4.12 Quantifying Ecosystem Services

4.12.1 Forest Biomass

In both experimental and reference conditions, forest biomass is predominately from existing *Metrosideros polymorpha* trees, the main canopy tree in remnant Hawaiian lowland wet forest ecosystems (Zimmerman et al. 2008). For the Slow Complementary treatment, biomass was 134,808 kilograms per hectare, over 80% of which was *M. polymorpha* (Table 7). Other native species such as *Diospyros sandwicensis* (14%) and *Psychotria hawaiiensis* (3.4%) were also important biomass contributors. Interestingly, *P. hawaiiensis* contributed to biomass from both established individuals as well as new recruit growth. In contrast, Reference plots at KMR contained 228,037 kg / ha of aboveground woody biomass per hectare (Table 8). Of this biomass, over half was within *M. polymorpha*, and the other canopy dominant, *D. sandwicensis* had 6.8%. The other species that were major contributors to biomass were all invasive: 8.4% was within *Ficus microcarpa*, 7.9% was within *Cecropia obtusifolia*, 6.6% was within *Macaranga mappa*, and 5.5% was within *Psidium cattleianum*.

Table 7. *Aboveground biomass composition of the 'Slow Complementary' treatment of hybrid wet forest restoration treatment at Keaukaha Military Reservation in Hilo, Hawai'i. Values are in kilograms per hectare. Existing are native trees found in the plot that were not cleared during experimental plot creation, while outplants were planted as part of the experimental treatment, and recruits are individuals that regenerated on their own over the last two years. Both* Pandanus tectorius *and* Pritchardia beccariana *lacked biomass that met our inclusion criteria and were excluded from analysis.*

Slow Complementary (kg / ha)		Origin	Existing	Recruit	Outplant	Combined
Aleurites	*moluccana*	Polynesian	0.00	0.00	34.64	34.64
Calophyllum	*inophyllum*	Polynesian	0.00	0.00	23.22	23.22
Mangifera	*indica*	Post-contact	0.00	0.00	42.43	42.43
Morinda	*citrifolia*	Polynesian	0.00	0.00	67.66	67.66
Persea	*americana*	Post-contact	0.00	0.00	114.67	114.67
Pipturus	*albidus*	Endemic	0.00	113.85	27.41	141.26
Rhus	*sandwicensis*	Endemic	0.00	6.60	843.14	849.74
Thespesia	*populnea*	Indigenous	0.00	0.00	17.90	17.90
Cibotium	*glaucum*	Endemic	803.58	0.00	0.00	803.58
Cibotium	*menziesii*	Endemic	353.73	0.00	0.00	353.73
Diospyros	*sandwicensis*	Endemic	19321.80	0.00	0.00	19321.80
Metrosideros	*polymorpha*	Endemic	108352.28	0.00	0.00	108352.28
Myrsine	*lessertiana*	Endemic	0.00	1.92	0.00	1.92
Psychotria	*hawaiiensis*	Endemic	4679.90	3.49	0.00	4683.39
Total	All species	Mixed	133511.28	125.87	1171.06	134808.21

Table 8. *Biomass composition in the unmanaged invaded reference plots of the hybrid wet forest restoration experiment at Keaukaha Military Reservation in Hilo, Hawai'i. Values are in kilograms per hectare for aboveground study target species biomass.* Clidemia hirta *did not produce biomass that met our inclusion criteria and was excluded from analysis.*

Reference (kg / ha)		Origin	Existing
Cecropia	*obtusifolia*	Invasive	18136.72
Cibotium	*glaucum*	Endemic	611.07
Cibotium	*menziesii*	Endemic	1226.03
Diospyros	*sandwicensis*	Endemic	15585.57
Ficus	*microcarpa*	Invasive	19200.43
Macaranga	*mappa*	Invasive	14508.34
Melastoma	*septemnervium*	Invasive	3474.81
Metrosideros	*polymorpha*	Endemic	137237.13
Myrsine	*lessertiana*	Endemic	1007.02
Psidium	*cattleianum*	Invasive	12749.51
Psychotria	*hawaiiensis*	Endemic	3420.02
Syzygium	*cumini*	Invasive	880.33
Total	All Species	Mixed	228036.97

4.12.2 Extractable and Stored Carbon

Potential carbon values were determined through two measures: carbon extracted in the form of sawn logs, chips, and pulp, and carbon stored on-site in living biomass. Extractable carbon results were greater for all measures in Reference plots, an extension of the 69% higher aboveground biomass in this treatment, most of which is concentrated in native *M. polymorpha* (Table 9; Table 10). Of these, the greatest potential measure was sawn timber, valued at $11,295. In contrast, aboveground carbon storage values for Slow Complementary conditions ranged from $10,777 to $2394 per hectare, while Reference plots ranged from $18,230 to $4051 per hectare (Table 11). Potential storage values are continuous, eclipsing potential extraction worth within the first year under higher value carbon payments or less than three years of lower value carbon payments. Further, less than 1% of on-site biomass in Slow Complementary plots originates from either outplants or new recruit growth, with *Rhus sandwicensis* and *Persea americana* respectively comprising the majority of each category. Both types are expected to continue storing additional carbon prior to maturity, further accelerating the likelihood that potential stored carbon values will be greater than extraction over time in the Slow Complementary treatment. Conversely, Reference plots are more static, with interactions between mature *M. polymorpha* and undesired invasives essentially stable and not expected to show significant changes total biomass (Table 9).

***Table 9**. Potential monetary values of extractable biomass for the 'Slow Complementary' hybrid wet forest restoration treatment at Keaukaha Military Reservation in Hilo, Hawai'i. Values refer to respective high and low values of sawn timber logs, wood chips, and wood pulp in dollars per hectare for study target species. Both* Pandanus tectorius *and* Pritchardia beccariana *lacked biomass that met our inclusion criteria and were excluded from analysis.*

Slow Complementary ($ / ha)		Sawlog H	Sawlog L	Chip H	Chip L	Pulp H	Pulp L
Aleurites	*moluccana*	1.72	1.48	0.85	0.80	1.02	0.95
Calophyllum	*inophyllum*	1.15	0.99	0.57	0.54	0.68	0.63
Mangifera	*indica*	2.10	1.82	1.04	0.98	1.25	1.16
Morinda	*citrifolia*	3.35	2.90	1.65	1.56	1.99	1.85
Persea	*americana*	5.68	4.91	2.80	2.64	3.37	3.13
Pipturus	*albidus*	7.00	6.05	3.45	3.25	4.15	3.86
Rhus	*sandwicensis*	42.09	36.39	20.74	19.58	24.98	23.20
Thespesia	*populnea*	0.89	0.77	0.44	0.41	0.53	0.49
Cibotium	*glaucum*	39.80	34.41	19.61	18.52	23.62	21.94
Cibotium	*menziesii*	17.52	15.15	8.63	8.15	10.40	9.66
Diospyros	*sandwicensis*	957.05	827.34	471.52	445.22	567.92	527.61
Metrosideros	*polymorpha*	5366.94	4639.55	2644.15	2496.71	3184.78	2958.70
Myrsine	*lessertiana*	0.10	0.08	0.05	0.04	0.06	0.05
Psychotria	*hawaiiensis*	231.98	200.54	114.29	107.92	137.66	127.89
Total	All species	6677.36	5772.37	3289.76	3106.32	3962.39	3681.11

***Table 10**. Potential extractable biomass values for the unmanaged invaded reference plots in the hybrid wet forest restoration experiment at Keaukaha Military Reservation in Hilo, Hawai'i. Values refer to respective high and low values of sawn timber logs, wood chips, and wood pulp in dollars per hectare for study target species.* Clidemia hirta *did not produce biomass that met our inclusion criteria and was excluded from analysis.*

Reference ($ / ha)		Sawlog H	Sawlog L	Chip H	Chip L	Pulp H	Pulp L
Cecropia	*obtusifolia*	898.35	776.60	442.60	417.92	533.09	495.25
Cibotium	*glaucum*	30.27	26.17	14.91	14.08	17.96	16.69
Cibotium	*menziesii*	60.73	52.50	29.92	28.25	36.04	33.48
Diospyros	*sandwicensis*	771.99	667.36	380.34	359.13	458.10	425.58
Ficus	*microcarpa*	951.04	822.15	468.55	442.43	564.35	524.29
Macaranga	*mappa*	718.63	621.23	354.05	334.31	426.44	396.17
Melastoma	*septemnerviun*	172.12	148.79	84.80	80.07	102.13	94.88
Metrosideros	*polymorpha*	6797.67	5876.37	3349.04	3162.29	4033.78	3747.43
Myrsine	*lessertiana*	49.88	43.12	24.57	23.20	29.60	27.50
Psidium	*cattleianum*	631.51	545.92	311.13	293.78	374.74	348.14
Psychotria	*hawaiiensis*	169.40	146.44	83.46	78.81	100.52	93.39
Syzygium	*cumini*	43.60	37.69	21.48	20.28	25.88	24.04
Total	All Species	11295.20	9764.35	5564.85	5254.54	6702.64	6226.84

***Table 11**. Potential economic benefits from extracting or storing carbon in the 'Slow Complementary' hybrid wet forest restoration treatment compared with unmanaged invaded reference plots at Keaukaha Military Reservation in Hilo, Hawai'i. Extracted carbon represents one-time removal, while stored carbon is continuous. Values are in dollars per hectare for combined study target species.*

$ / ha	Slow Complementary	Site Reference
Sawlog High	6677.36	11295.20
Sawlow Low	5772.37	9764.35
Chip High	3289.76	5564.85
Chip Low	3106.32	5254.54
Pulp High	3962.39	6702.64
Pulp Low	3681.11	6226.84
Stored High	10777.01	18230.02
Stored Low	2394.89	4051.12

4.12.3 Biodiversity

Initially, potential biodiversity payments were estimated for experimental treatment and reference conditions using calculations from similar contexts in tropical Australia. Study results therein include high and low values of approximately $23 and $7 per hectare of wet tropical forest for a developed area (Curtis 2004 in Van der Ploeg & de Groot 2010). In either case, on-site biodiversity values ranged from $2.02 to $0.67 in respective high and low circumstances, necessitating another method of differentiation as this protocol does not differentiate between restored or invaded conditions. Using our species origin-based biomass approach (BioValue), the Slow Complementary treatment ranged from $13,456 to $2990, while worth of the Reference conditions ranged between $17,275 and $3838 at this stage of the experiment. These values are 24.8% more for Slow Complementary treatments and 5.5% less for Reference plots than without considering biodiversity, supporting Hypothesis 2. Endemic species dominated existing biomass in both treatment types (Table 12; Table 13; Figure 35; Figure 36). In Slow Complementary plots, endemics comprised the entirety of recruits while also dominating outplant biomass (Table 6). Polynesian origin, post-contact, and indigenous origin species, while important for experimental conditions, have not yet significantly contributed to biomass in the Slow Complementary treatment and were entirely absent from the Reference site (Table 12; Table 13). Rather, Reference sites were exclusively pre-existing endemic or invasive biomass (Table 13).

***Table 12**. Potential stored carbon monetary values and carbon values weighted per hectare using the proposed 'BioValue' method for the 'Slow Complementary' treatment at Keaukaha Military Reservation in Hilo, Hawai'i. Weighted values indicate importance beyond storing carbon including utilitarian, cultural, and native. Biomass is in kilograms per hectare, while dollar amounts are based on carbon values.*

Slow Complementary	Existing (kg)	Recruit (kg)	Outplant (kg)	Combined (kg)	Store H ($)	Store L ($)	BioFactor	BioValue (kg)	BV Hi ($)	BV Lo ($)
Endemic	133511.28	125.87	870.55	134507.70	10752.98	2389.55	1.25	168134.62	13441.23	2986.94
Indigenous	0	0	17.90	17.90	1.43	0.32	1.00	17.90	1.43	0.32
Polynesian	0	0	125.52	125.52	10.03	2.23	0.75	94.14	7.53	1.67
Post-contact	0	0	157.10	157.10	12.56	2.79	0.50	78.55	6.28	1.40
Invasive	0	0	0	0	0	0	0.25	0	0	0
Total	133511.28	125.87	1171.06	134808.21	10777.01	2394.89	1.25	168325.21	13456.47	2990.33

Table 13. *Potential stored carbon monetary values and carbon values weighted using the proposed 'BioValue' method for unmanaged invaded reference plots at Keaukaha Military Reservation in Hilo, Hawaiʻi. Weighted values indicate importance beyond storing carbon including utilitarian, cultural, and native. Biomass is in kilograms per hectare, while dollar amounts are based on carbon values.*

Site Reference	Existing (kg)	Recruit (kg)	Outplant (kg)	Combined (kg)	Store H ($)	Store L ($)	BioFactor	BioValue (kg)	BV Hi ($)	BV Lo ($)
Endemic	159086.84	0	0	159086.84	12717.92	2826.20	1.25	198858.55	15897.40	3532.76
Indigenous	0	0	0	0	0	0	1.00	0	0	0
Polynesian	0	0	0	0	0	0	0.75	0	0	0
Post-contact	0	0	0	0	0	0	0.50	0	0	0
Invasive	68950.13	0	0	68950.13	5512.10	1224.91	0.25	17237.53	1378.02	306.23
Total	228036.97	0	0	228036.97	18230.02	4051.12	0.95	216096.08	17275.43	3838.98

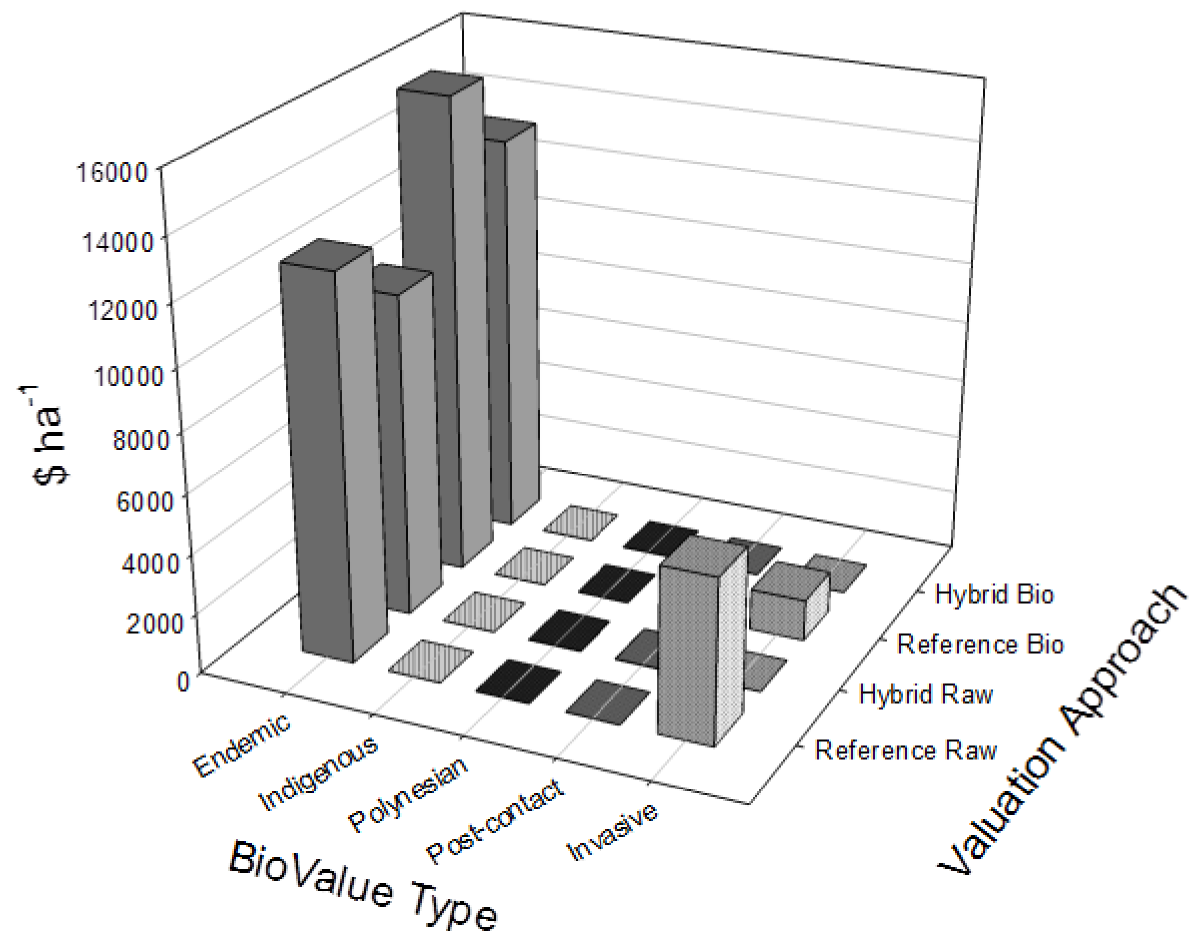


Figure 35. *Potential stored carbon high monetary values and carbon values weighted using the proposed 'BioValue' method for the Liko Nā Pilina restoration experiment at Keaukaha Military Reservation in Hilo, Hawaiʻi. Categories include invasive, species introduced post-contact, species introduced by Polynesian settlers, indigenous, and endemic natives. The Hybrid Slow Complementary treatment lacked invasive species, while the invaded Reference lacked indigenous, Polynesian, and post-contact origin species. Values are in dollars per hectare.*

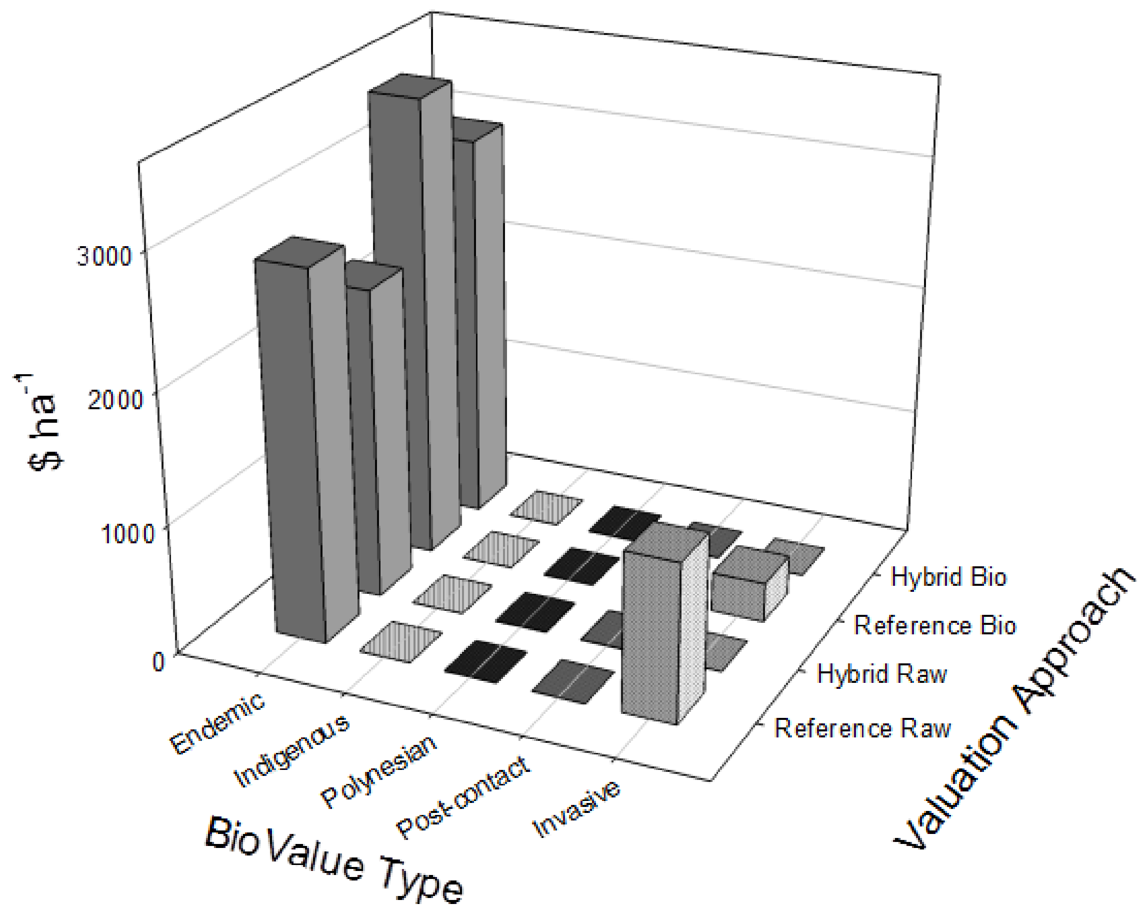


Figure 36. *Potential stored carbon low monetary values and carbon values weighted using the proposed 'BioValue' method for the Liko Nā Pilina restoration experiment at Keaukaha Military Reservation in Hilo, Hawai'i. Categories include invasive, species introduced post-contact, species introduced by Polynesian settlers, indigenous, and endemic natives. The Hybrid Slow Complementary treatment lacked invasive species, while the invaded Reference lacked indigenous, Polynesian, and post-contact origin species. Values are in dollars per hectare.*

4.12.4 Labor and Project Materials

Labor needed to establish and maintain project conditions was approximately $21,735 per treatment type, or $135,844 per hectare (Table 14; Figure 35). Labor includes reconnaissance and surveying prior to plot establishment ($912), invasive species clearing and removal ($5869), preparation and plant propagation ($2591), and two years of post-establishment plot maintenance ($9641). While required for conceptual validation, labor costs for experimental study aspects were excluded from this analysis. To utilize this labor, some $15,790 was spent on materials (Table 14). The most expensive components were externally-sourced plants ($9500), potting soil ($859), Garlon (Triclopyr) herbicide ($710), and hand loppers ($621). Many species were established in greenhouses from on-site or nearby seeds or cuttings, but most outplants had to be purchased from local growers. Potting mix, amended with cinder, was needed for transplanting young propagules into plot areas lacking mature forest floor-like soil conditions. Concentrated

Garlon, crop oil for dilution, and herbicide dye were necessary for control of particularly aggressive or species otherwise responding favorably to cleared plots. Loppers, like many other hand tools, proved to have a short lifespan when faced with site moisture and humidity. Similarly, power tool maintenance ($528) was also a notable cost for site establishment due in part to rugged site conditions and high plant productivity. After fifty years, projected labor and material investments range between $268,915 and $95,372 ($1.69 million and $600,000 per hectare; Table 14).

Table 14. *Projected investment investments in dollars per hectare for the 'Slow Complementary' treatment at Keaukaha Military Reservation in Hilo, Hawai'i. Investments include pre-project establishment requirements, two years of project maintenance, and potential remaining labor investments at 100%, 75%, 50%, and 25% of current rates on a 50-year management timeframe.*

Slow Comp	Materials	Current	48 yr Labor	50 yr total
100%	98,688	135,844	1,446,189	1,680,721
75%	98,688	135,844	1,084,641	1,319,173
50%	98,688	135,844	723,095	957,626
25%	98,688	135,844	361,547	596,079

4.12.5 Return on Investment

When accounting for estimated expenditures over longer terms, project return on investment varied based on carbon storage income as well as including or excluding biodiversity from income. With higher carbon market rates and a favorable labor decrease (25% of current rates), stored carbon alone presents an investment return of approximately 56 years (Table 15). Including biodiversity results in an economic recovery period of approximately 45 years, supporting Hypothesis 3 within a 50-year management timeframe. In contrast, lower market rates and no labor input changes result in approximate investment recovery periods of 702 years for carbon value alone or 563 years when including biodiversity. Differing carbon values would necessarily affect recovery times, as would alternate biodiversity weightings, unanticipated labor increases, or absorbing other unforeseen circumstances such as site damage, disease, or effects of climate change.

Table 15. *Time in years for return on investment in the 'Slow Complementary' treatment at Keaukaha Military Reservation in Hilo, Hawai'i. Investments include pre-project establishment requirements, two years of project maintenance, and potential remaining labor investments at 100%, 75%, 50%, and 25% of current rates on a 50-year management timeframe. Returns include high and low carbon storage market values for raw biomass as well as biomass modified using the proposed 'BioValue' technique.*

Slow Comp	Stored H	Stored L	BioValue H	BioValue L
100%	155.95	701.79	124.90	562.05
75%	122.41	550.83	98.03	441.15
50%	88.86	399.86	71.16	320.24
25%	55.31	248.90	44.30	199.34

4.13 Outreach Activities

4.13.1 Visitation

We calculated that from the beginning of 2013 to the end of June 2016 there were 978.5 volunteer hours contributed to the project. Included in these hours are visits by various educational groups that participated in service learning. These included visits by undergraduate students (Semester at Sea, Cal Poly Ponoma, University of Hawaiʻi (UH) Hilo Pacific Island Program for Exploring Science, UH Hilo International and National Student Exchange), K-12 students (Nā Pua Noʻeau, Ka ʻUmeke Kāʻeo School, ʻImi Pono no ka ʻĀina), and USDA Forest Service administrative staff.

4.13.2 Training Opportunities

Our project has provided numerous opportunities for student interns (see Appendix 1). Through the Hawaiʻi Community College Forest Team program we have hosted 7 interns (Matt Kahoʻohanohano, Ashley ʻKalei' Shaw, Jeff Pieper, Cole Rogers, Kahealani Wailani-Nihipali, Jayson Warden, Taite Winthers-Barcelona). Taite was later offered a student position with the USDA Forest Service. Through Stanford University we have had 6 interns (Chris Chu, Clara Luu, Alexandra Lincoln, and Cole Stites-Clayton, Jana Kaopuiki, Palani Akana). We have also hosted four students as part of the UH Hilo Research Experiences for Undergraduate grant, organized by the Pacific Internship Program for Exploring Science (PIPES). Malia Stewart (UH Mānoa) conducted a project on the functional traits of native and non-native species within our plots. Iván Martes (UPR Mayagüez) compared levels of herbivory between native and non-native species at KMR and a less invaded forest area at Keauʻohana Forest Reserve. Stephen McAuliffe (Humboldt State) did a complementary project assessing the arthropod populations at the two sites. He presented his research in a poster at the Conference for Undergraduate Research in Arlington, VA in November 2013. Bronson Palupe (UH Hilo) conducted a project that examined the effect of a'a lava substrate roughness on outplant growth and survival. The USDA's Forest Services Office of International Programs has an International Visitor Program which has provided us with four interns from Germany (Catharine Cohrs, Steffen Wolff, Hanna Rhein, and Lena Daniel) and one from Denmark (Lasse Lybaek).

We have also provided training for two UH Hilo graduate students. Corie Yanger worked on the project for one year as a research assistant. Jodie Schulten worked on the project for 1.5 years as a research assistant and also conducted her M.S. research at the site, comparing light environments in native-dominated forests, invaded forests which still contain native cover, and forests with entirely non-native species and determined the light conditions most conducive for native seedling establishment. Two USDA Forest Servive post-docs, Laura Warman and Donald Rayome were trained on this project and are currently working on writing manuscripts.

4.13.3 Publicity

Our project featured in various media outlets. There have been three newspaper articles in Hawaiʻi newspapers, USDA Forest Service Press release, a personal narrative piece from a volunteer in the newsletter Environment Hawaiʻi, and a video made by the University of Hawaiʻi system, which was also picked up by KITV news (see Appendix 2).

5. Conclusions and Implications for Future Research/Implementation

5.1 General Conclusions

In Hawaiian lowland wet forest, restoring to a 100% native state is not feasible (Cordell et al. 2016), which spurred an alternative approach (Ostertag et al. 2015). The early results of this experiment show that the treatments have a drastically different environment than the invaded reference condition, with large increases in light availability and recruitment of new individuals. It is also encouraging that survival rates are higher than those recorded by other restoration experiments in Hawaiʻi. In an earlier outplanting experiment at the same site, survival under high light conditions was 81% of *Myrsine lessertiana*, 50% for *Metrosideros polymorpha*, and 80% for *Psychotria hawaiiensis* (Schulten et al. 2014). In drier ecosystems in Hawaiʻi, survival has been lower (e.g., lowland dry forest, 12-63%, Cordell et al. 2008; woodlands 9-31%, Yelenik et al. 2014). In the Liko Nā Pilina experiment, six species had 100% survival. These high survival rates may be due in part to the careful process by which species were chosen, emphasizing a species' appropriateness for the environment (Ostertag et al. 2015). The two Redundant treatments had the best survival, but the Slow Redundant treatment also had the lowest growth, suggesting a potential tradeoff between growth and survival. It would be logical to prioritize survival over growth, but for our restoration objectives it is also a priority to create a canopy and produce a light environment that shades out the undesired species. Achieving the correct light environment is crucial because work in a variety of lowland wet forests showed that all seedlings, both native and non-native, prefer areas of moderate light quality (red:far red values of 0.41-0.70) (Rosam 2015).

In the 2016 IPR, we were asked to clearly define your success metrics and comparatively describe your outcomes against those metrics. Although all the ecosystem functioning metrics we are measuring are useful, we argue that the key metrics are survival and growth. Our other metrics such as litterfall, soil nutrients, and light availability are all factors that may influence these two crucial metrics. A restoration practitioner might ask the minimum acceptable survival rate at these early stages, once the cost of outplants and labor expended into growing and planting them is taken into account. Given that all treatments had relatively high survival, an argument can be made for the Moderate Redundant treatment as best during the short-term. However, an additional consideration is that fast-growing species, and the Moderate treatments in particular, are more likely to include species whose life histories affect the environment (effect traits, Suding et al. 2008) in such a way that may not sustain the planted species mix in the long-term. Fast growth rates are linked to fast rates of nutrient cycling, especially for invasive species (Ehrenfeld 2003, Allison and Vitousek 2004), and indeed the need to slow down nutrient cycling rates to discourage invasion was an impetus for this experimental design. Many other things are not different among the treatments yet (litterfall, degree of invasion, seed inputs) but it is noteable that there is more fruiting and flowering in the Complementary treatments. Therefore, the Slow Complementary treatment may be the best compromise, at least at this early date.

Can an approach based on functional traits provide a useful paradigm for restoration? The approach could be applied in many contexts, such as reclamation, in areas where new stable states prevent natural recovery (i.e., nutrient/water/fire disturbance regimes introduced or removed) or in ecosystems especially vulnerable to climate change. The functional trait-based restoration approach of this experiment is very similar to the suggested trait-based models for restoration put forth by Laughlin (2014), except that in those models, community-weighted

means are used to estimate the optimal abundance of each species. In this experiment, we focused on maximizing or minimizing functional dispersion in a hybrid ecosystems context. We concentrated on hybrid ecosystems because on islands, novel combinations of species are a common outcome of a sudden high rate of species introductions into species-poor systems (Ewel et al. 2013). Many of these hybrid ecosystems are considered to be "unfortunate reality" (sensu Hobbs et al. 2014) restoration scenarios, although little is known about the long term stability or dynamics of these ecosystems. Unlike many mainland sites, hybrid ecosystems on oceanic islands represent a unique chance to understand the histories and development of invasions and new species assemblages. Using non-native species in restoration is still a controversial idea, and we make note that the species chosen were all present both on the island and in the general climatic and ecosystem type and many of them were Polynesian introductions that have been naturalized over the last 1000 years or so. Given how little is known about the role of non-native species, we see three potential outcomes to the experiment: 1) we meet the goals of the experiment and the treatments develop into ecosystems that function in more desirable ways than the reference (including increased invasion resistance); 2) the treatments provide desirable ecosystem services but not invasion resistance; or 3) we go backwards and end up with ecosystems that function less desirably than the present invaded forest. We consider that the third scenario is quite unlikely, given that the species outplanted all have more favorable environmental effects (including N cycling) than the invasive species they are replacing. Thus, given the early indicators and success so far (mainly in the form of high survival rates), we propose that using functional trait-based restoration is a promising option for restoration, especially in sites where few other options are available.

5.2 Implications for Future Research

Deciding on which mix of native and exotic species is best is in part based on outplant survival and growth, but must also factor in how species' traits will affect the environment in the long-term. Experiments that manipulate the functional mix of species are needed in structurally complex ecosystems, and they can provide both short-term and long-term benefits to the understanding of community assembly processes. In addition, a very important need is to get more functional trait data into REST, for Hawaiʻi and globally. The program's utility is directly related to how much data is in it, because managers will not have the time or the means to collect their own data in many cases.

5.3 Implementation

Our results are applicable throughout LWF in Hawaiʻi. Most importantly, our results will directly help the military meet the stewardship responsibilities of Army National Guard land by providing guidance on species choice in restoration. The approach could be applied to other heavily-invaded DoD sites to guide these areas toward lower intensity, more sustainable, and cost-effective management in the long-term. With REST, there is the ability to test the four restoration objectives currently described within the program: successional facilitation, fire tolerance, drought tolerance, and carbon storage. Restoring for successional facilitation creates conditions that increase the likelihood of past (or desired) ecosystem states recovering in light of invasion pressures. Similarly, restoring with fire or drought in mind supports returns to a resilient community capable of adapting to expected increases in fire and drought resulting from climate change. Finally, with appropriate species selection, maximizing carbon storage can allow for multi-purpose restoration that promote long-term emission offsets while still meeting on-site

biodiversity and human mobility requirements. Conducting further demonstrations in Hawaiʻi would capitalize on Hawaiian island ecosystem characteristics including favorable growing climate, known species introduction dates, and the ability to plant species combinations that cannot be compared elsewhere, either from ecological, ethical (risk of species' introductions), or logistical concerns.

Products and information provided include:

1) Survival rates for native and exotic LWF species
2) A detailed assessment of time and costs for all restoration activities within the project
3) The REST program
4) Publications and presentations about effects of forest restoration using a functional trait-based approach.

6. Literature Cited

Allison, S. D., and P. M. Vitousek. 2004. Rapid nutrient cycling in leaf litter from invasive plants in Hawai'i. Oecologia 141: 612-619.

Asner, G.P., R.F. Hughes, J. Mascaro, A. Uowolo, D.E. Knapp, J. Jacobsen, T. Kennedy-Bowdoin, and J.K. Clark. 2011. High-resolution carbon mapping on the million-hectare island of Hawaii. Frontiers in Ecology and the Environment 9: 434−439.

Bhaskar, R., T.E. Dawson, and P. Balvanera. 2014. Community assembly and functional diversity along succession post-management. Functional Ecology 28: 1256–1265.

Chave, J., D. Coomes, S. Jansen, S.L. Lewis, N.G. Swenson, and A.E. Zanne. 2009. Towards a worldwide wood economics spectrum. Ecology Letters 12: 351-366.

Cornelissen, J. H. C., S. Lavorel, E. Garnier, S. Díaz, N. Buchmann, D.E. Gurvich, P.B. Reich, H.T. Steege, H.D. Morgan, M.G.A.V.D. Heijden, J.G. Pausas, and H. Poorter. 2003. A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Australian Journal of Botany 51: 335 - 380.

Cordell S., M. McClellan, Y. Y. Carter, and L. J. Hadway. 2008. Towards restoration of Hawaiian tropical dry forests: the Kaupulehu outplanting programme. Pacific Conservation Biology 14:279–284.

Cordell, S., R. Ostertag, B. Rowe, L. Sweinhart, L. Vasquez-Radonic, J. Michaud, T. C. Cole, and J. R. Schulten. 2009. Evaluating barriers to native seedling establishment in an invaded Hawaiian lowland wet forest. Biological Conservation 142:2997–3004.

Cordell, S., R. Ostertag, J. Michaud, and L. Warman. 2016. Quandaries of a decade long restoration experiment trying to reduce invasive species: Beat them, join them, give up, or start over? Restoration Ecology 24: 139-144.

Crossman, N.D, B.A. Bryan and D.M. Summers. 2011. Carbon payment and low-cost conservation. Conservation Biology 25: 835−845.

Cuddihy, L.W., and C.P. Stone. 1990. Alteration of native Hawaiian vegetation: effects of humans, their activities, and introductions. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Honolulu, HI.

Curtis, I.A. 2004. Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. Ecological Economics 50: 163–194.

Daehler, C.C., J.S. Denslow, S. Ansari, and H. Kuo. 2004. A risk assessment system for screening out invasive pest plants from Hawai‘i and other Pacific Islands. Conservation Biology 18: 360-368.

Denslow, J.S. 2003. Weeds in paradise: Thoughts on the invasibility of tropical islands. Annals of the Missouri Botanical Garden 90: 119-127.

Díaz, S. and M. Cabido. 2001. Vive la difference: plant functional diversity matters to ecosystem processes. Trends in Ecology and Evolution 16: 646–655.

Donovan, L.A., H. Maherali, C.M. Caruso, H. Huber, and H. de Kroon. 2011. The evolution of the worldwide leaf economics spectrum. Trends in Ecology and Evolution 26: 88–95.

Ehrenfeld, J. G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems 6:503-523.

Ewel, J.J., and F.E. Putz. 2004. A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment 2: 354–360.

Ewel, J.J., J. Mascaro, C. Kueffer, A. E. Lugo, L. Lach, and M. R. Gardener. 2013. Islands: Where novelty is the norm. Pages 29-44 in R. J. Hobbs, E. S. Higgs, and C. A. Hall, editors. Novel ecosystems: Intervening in the new ecological world order. Wiley-Blackwell, Oxford, UK.

Funk J.L., E.E. Cleland, K.N. Suding, and E.S. Zavaleta. 2008. Restoration through reassembly: plant traits and invasion resistance. Trends in Ecology and Evolution 23: 695–703.

Giambelluca, T.W., Q. Chen, A. G. Frazier, J.P. Price, Y.-l. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte. 2013. Online rainfall atlas of Hawaiʻi. Bulletin of the American Meteorological Society 94: 313-316.

Giambelluca, T.W., X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. Evapotranspiration of Hawaiʻi. Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawaiʻi.

Guo, Q. and A. Symstad. 2008. A two-part measure of degree of invasion for cross-community comparisons. Conservation Biology 22: 666–672.

.

Hobbs, R.J., E.S. Higgs, and J.A. Harris. 2014. Novel ecosystems: concept or inconvenient reality? A response to Murcia et al. Trends in Ecology and Evolution 29: 645-646.

Hooper, D.U. and J.S. Dukes. 2010. Functional composition controls invasion success in a California serpentine grassland. Journal of Ecology 98: 764–77.

Hughes, R.F. and J.S. Denslow. 2005. Invasion by a N2-fixing tree alters function and structure in wet lowland forests of Hawai'i. Ecological Applications 15: 1615-1628.

Jepson Flora Project. 2006. Ecological Flora of California. Available from: <http://ucjeps.berkeley.edu/efc/dbase.html>. Last accessed: 11 Jul 2016.

Kattge et al. 2011. TRY – a global database of plant traits. Global Change Biology 17: 2905−2935.

Keith, L. M., R. F. Hughes, L. S. Sugiyama, W. P. Heller, B. C. Bushe, and J. B. Friday. 2015. First Report of *Ceratocystis* wilt on ʻŌhiʻa. Plant Disease. http://dx.doi.org/10.1094/PDIS-12-14-1293-PDN.

Kirch, P.V. 2002. On the road of the winds: An archaeological history of the Pacific Islands before European contact. University of California Press, Berkeley, CA.

Laliberté, E., and B. Shipley. 2012. FD: measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1.0-11.

Laughlin, D. 2011. Nitrification is linked to dominant leaf traits rather than functional diversity. Journal of Ecology 99: 1091-1099.

Laureto, L.M. Orlandi, M. Vinicius Cianciaruso, and D.S. Menezes Samiac. 2015. Functional diversity: an overview of its history and applicability. Natureza and Conservação: Brazilian Journal of Nature Conservation 13: 112–116.

Leffler, A.J., J.J. James, T.A. Monaco, and R.L. Sheley. 2014. A new perspective on trait differences between native and invasive exotic plants. Ecology 95: 298-305.

Litton, C.M., D.R. Sandquist and S. Cordell. 2006. Effects of non-native grass invasion on aboveground carbon pools and tree population structure in a tropical dry forest of Hawaii. Forest Ecology and Management 231: 105-113.

Northfield, T.D., G.B. Snyder, A.R. Ives, and W.E. Snyder. 2010. Niche saturation reveals resource partitioning among consumers. Ecology Letters 13: 338–348.

OANDA. 2016. Average exchange rates. Available from: <http://www.oanda.com/currency/average>. Last accessed: 16 Feb 2016.

Ordonez, A. 2014. Functional and phylogenetic similarity of alien plants to co-occurring natives. Ecology 95: 1191-1202.

Ostertag, R., S. Cordell, J. Michaud, T.C. Cole, J.R. Schulten, K.M. Publico, and J.H. Enoka. 2009. Ecosystem and restoration consequences of invasive woody species removal in Hawaiian lowland wet forest. Ecosystems 12: 503-515.

Ostertag, R., F. Inman-Narahari, S. Cordell, C.P. Giardina, and L. Sack. 2014. Forest structure in low-diversity tropical forests: a study of Hawaiian wet and dry forests. PLoS ONE 9(8): e103268, doi:10.1371/journal.pone.0103268.

Ostertag, R., L. Warman, S. Cordell, and P.M. Vitousek. 2015. Using plant functional traits to restore Hawaiian rainforest. Journal of Applied Ecology 52: 805-809.

Ostertag R., D. Rayome, S. Cordell, P. Vitousek, B. Fung, P. Pante, R. Tate, and A. Vizzone. 2016. Restoring Ecosystem Services Tool (REST) User Guide, V 1.3. Prepared for SERDP project RC-2117 by the University of Hawaii at Hilo, USDA Forest Service, and Stanford University.

Paula S, and J.G. Pausas. 2013. BROT: a plant trait database for Mediterranean Basin species. Version 2013.06. Available From: <http://www.uv.es/jgpausas/brot.htm>. Last accessed: 11 Jul 2016.

Peck, J.E. 2010. Multivariate analysis for community ecologists, MjM Software, Gleneden Beach, Oregon, USA.

Price, J. S.M. Gon II, J.D. Jacobi, and D. Matsuwaki. 2007. Mapping plant species ranges in the Hawaiian Islands: Developing a methodology and associated GIS layers. Hawai`i Cooperative Studies Unit Technical Report HCSU-008, p. 58.

Reich, P.B., D.S. Ellsworth, M.B. Walters, J. Vose, C. Gresham, J. Volin, and W. Bowman. 1999. Generality of leaf traits relationships: a test across six biomes. Ecology 80:.1955-1969.

Reich, P.B., I. Wright, J. Cavender-Bares, J. Craine, J. Oleksyn, M. Westoby, and M.B. Walters. 2003. The evolution of plant functional variation: traits, spectra, and strategies. International Journal of Plant Sciences 164:s143-164.

Reich, P.B. 2014. The world-wide ‘fast–slow’ plant economics spectrum: a traits manifesto. Journal of Ecology 102: 275-301.

Rey Benayas, J.M., A.C. Newton, A. Diaz, and J.M. Bullock. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science 325:121-1124.

RISI. 2015. World timber price quarterly. Available from: <www.risiinfo.com/Marketing/ Commentaries/world_timber.pdf>. Last accessed: 17 Feb 2016.

Rosam, J.R. 2015. Assessment of light quality, variability, and seedling presence in Hawaiian lowland wet forests. University of Hawai‘i at Hilo, Hilo, HI.

Schlaepfer, M.A., D.F. Sax, and J.D. Olden. 2011. The potential conservation value of non-native species. Conservation Biology 25:428-437.

Schleuter, D., M. Daufresne, F. Massol, and C. Argillier. 2010. A user’s guide to functional diversity indices. Ecological Monographs 80: 469 - 484.

State of Hawai‘i. 2016. Wage Standards Division: minimum wage and overtime. Available from: <http://labor.hawaii.gov/wsd/minimum-wage/>. Last accessed: 15 Mar 2016.

Schulten, J.R., T. Colleen Cole, S. Cordell, K. M. Publico, R. Ostertag, J. Enoka, and J. D. Michaud. 2014. Persistence of native trees in an invaded Hawaiian lowland wet forest: experimental evaluation of light and water constraints. Pacific Science **68**:267-285.

Suding, K.N., S. Lavorel, F.S. Chapin, J.H.C. Cornelissen, S. Díaz, E. Garnier, D. Golberg, D.U. Hooper, S.T. Jackson, M-L. Navas. 2008. Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. Global Change Biology14: 1125–1140.

Swenson, N. G., and B. J. Enquist. 2008. The relationship between stem and branch wood specific gravity and the ability of each measure to predict leaf area. American Journal of Botany 95: 516-519.

The Nature Conservancy. 2016. “Potential Carbon Markets in Hawaii." Institute for Pacific Islands Forestry, Hilo, HI. 4 Mar 2016.

Trusdell, F.A., E.W. Wolfe, and J. Morris. 2005. Digital database of the geologic map of the Island of Hawaii. U.S. Geological Survey Data Series 144.

USDA NRCS. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC, USA. Available from: <http://plants.usda.gov>. Last accessed: 11 Jul 2016.

Van der Ploeg, S. and R.S. de Groot. 2010. The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, The Netherlands.

Vitousek, P.M., and L.R. Walker. Biological invasion by Myrica faya in Hawai’i: plant demography, nitrogen fixation, and ecosystem effects. Ecological Monographs 59: 247-265.

Wagner, W.L., D.R. Herbst, and S.H. Sohmer. 1999. Manual of the flowering plants of Hawaii. University of Hawaii Press and Bishop Museum Press Honolulu, HI.

Walker, B.H. 1992. Biodiversity and ecological redundancy. Conservation Biology 6: 18–23.

Walker, B.H. 1995. Conserving biological diversity through ecosystem resilience. Conservation Biology 9: 747–52.

Woodcock, D. 2003. To restore the watersheds: Early 20th Century tree planting in Hawaii. Annals of the Association of American Geographers 93: 624-635.

Wright, I.J., P.B. Reich, J.H.C. Cornelissen, D.S. Falster, E. Garnier, K Hikosaka et al. 2005. Assessing the generality of global leaf trait relationships. New Phytologist 166: 485-496.

Yelenik, S. G., N. DiManno, and C. M. D'Antonio. 2015. Evaluating nurse plants for restoring native woody species to degraded subtropical woodlands. Ecology and Evolution **5**:300-313.

Zanne, A. E., D.C. Tank, W.K. Cornwell, J.M. Eastman, S A. Smith, R.G. Fitzjohn, D.J. Mcglinn, B.C. O'meara, A.t. Moles, P.B. Reich, D.L. Royer, D.E. Soltis, P.F. Stevens, M. Westoby, I.J. Wright, L. Aarssen, R.I. Bertin, A. Calaminus, R. Govaerts, F. Hemmings, M.R. Leishman, J. Oleksyn, P.S. Soltis, N.G. Swenson, L. Warman, and J.M. Beaulieu. 2014. Three keys to the radiation of angiosperms into freezing environments. Nature 506: 89-92.

Zedler, J.B., J.M. Doherty, and N.A. Miller. 2012. Shifting restoration policy to address landscape change, novel ecosystems, and monitoring. Ecology and Society 17 (4):36, www.ecologyandsociety.org/vol17/iss4/art36/.

Zimmerman, N., R.F. Hughes, S. Cordell, P. Hart, H.K. Chang, D. Perez, R.K. Like, and R. Ostertag. 2008. Patterns of primary succession of native and introduced plants in lowland wet forests in Eastern Hawai'i. Biotropica 40: 277-284.

7. Appendices

Appendix 1. Project participants to date from inception to August 2016.

<u>Research Team</u>

Susan Cordell	USDA Forest Service, Institute of Pacific Islands Forestry
Rebecca Ostertag	University of Hawaiʻi at Hilo, Biology
Laura Warman	USDA Forest Service, Institute of Pacific Islands Forestry
Peter Vitousek	Stanford University
Jené Michaud	University of Hawaiʻi at Hilo, Geology
Jodie Schulten	University of Hawaiʻi at Hilo, Biology
Amanda Uowolo	USDA Forest Service, Institute of Pacific Islands Forestry
William Buckley	Stanford University
Corie Yanger	University of Hawaiʻi at Hilo, Biology
Taite Winthers-Barcelona	USDA Forest Service, Institute of Pacific Islands Forestry
Nicole DiManno	University of Hawaiʻi at Hilo, Biology
Leif Mortensen	USDA Forest Service, Insitute of Pacific Islands Forestry
James Crisp	USDA Forest Service, Institute of Pacific Islands Forestry
Kai McGuire-Turcotte	University of Hawaiʻi at Hilo
Donnie Rayome	USDA Forest Service, Institute of Pacific Islands Forestry

<u>Student Projects and Internships through 2016:</u>

Catharine Cohrs	Eberswalde University for Sustainable Development, Germany
Steffen Wolff	University of Potsdam, Germany
Matt Kahoʻohanohano	Hawaiʻi Community College
Alexandra Lincoln	Ponoma College
Clara Luu	Stanford University
José Iván Martinez Martes	Universidad de Puerto Rico
Stephen McAuliffe	Humboldt State University
Jeff Pieper	Hawaiʻi Community College
Cole Rodgers	Hawaiʻi Community College
Ashley Shaw	Hawaiʻi Community College
Malia Stewart	University of Hawaiʻi at Mānoa
Jason Warden	University of Hawaiʻi at Hilo
Chris Chu	Stanford University
Cole Stites-Clayton	Stanford University
Kevin Alison	University of Hawaiʻi at Hilo, Agriculture major
David Nourry	Groupe Synergis Consulting, Quebec, Canada
Katia Chikasuye	B.A. from University of San Francisco
Erin Datlof	B.A. from University of Hawaiʻi at Hilo
Kaikea Blakemore	B.A. from University of Hawaiʻi at Hilo, M.A. from Naropa Univ.
Jana Kaopuiki	Stanford University
Lasse Lybaek	University of Copenhagen, Denmark
Akuila Smau	University of Hawaiʻi at Hilo, Agriculture major

Taylor Warner	University of Hawai‘i at Hilo, Environmental Studies major
Sayaalii Baker	University of Hawai‘i at Hilo, Environmental Studies major
Rebecca Carpenter	B.S. from University of Hawai‘i at Hilo
Christa Nichols	University of Hawai‘i at Hilo, Environmental Studies major
Joanna Norton	University of Hawai‘i at Hilo, M.S. Candidate
Meike Becker	Georg-August University, Göttingen, Germany
Julianne Lutze	Hochschule Bremen University, Germany
Mirja Bauer	Georg-August University, Göttingen, Germany
Talita Antunes Maia	Brazil Scientific Mobility Program, Instituto de Biociências, Letras e Ciências Exatas (IBILCE/UNESP), Brazil
Karen Kacurin	Brazil Scientific Mobility Program, Federal University of Alagoas, Alagoas, Brazil
Lais de Paula Kheir Eddine	Brazil Scientific Mobility Program, Federal Uberlandia University, Brazil
Hanna Rhein	University of Sustainable Development, Eberswalde, Germany
Lena Daniel	University of Sustainable Development, Eberswalde, Germany
Palani Akana	Stanford University
Shawna Blackford	Hawai‘i Community College
Mika Gallardo	Hawai‘i Community College
Celine Jennison	Oxford University, UK
Sarah Chavez-Inman	B.S. University of California, Santa Barbara
Israel Stillman	University of Hawai‘i at Hilo, Forestry major
James Melcher	University of Hawai‘i at Hilo, Geography major
Bronson Palupe	University of Hawai‘i at Hilo, Geography major
Angalee Kirby	University of Hawai‘i at Hilo, M.S. candidate

Appendix 2. Publicity based on the Liko Nā Pilina project.

TV:
Aired Dec 5, 2013 on 10 pm news: http://www.kitv.com/page/search/htv-hon/news/hawaii/UH-Hilo-students-take-on-reforestation-project/-/8905354/23348910/-/qb3neiz/-/index.html

UH Web and Video:
http://www.hawaii.edu/news/2013/11/12/could-hybrid-ecosystems-save-native-forests-in-hawaii/

http://hilo.hawaii.edu/blog/chancellor/2013/11/13/research-uh-hilo-ecosystems/

UH Video Only:
http://www.youtube.com/watch?v=6Ww3-F7wphk&feature=youtu.be

Article in Nautilus magazine:
http://nautil.us/blog/ecologists-cant-beat-invasive-species-so-theyre-joining-them

Susan Cordell After Dark In the Park presentation:
http://www.nps.gov/havo/planyourvisit/20131105_after_dark.htm

SERDP newsletter: email 22 Sep 2014
http://www.serdp-estcp.org/News-and-Events/Blog/A-Novel-Ecosystem-Approach-to-Maintaining-Native-Forest-Communities

USDA Climate Hub (May 2015):
http://climatehubs.oce.usda.gov/southwest-hub/southwest-climate-hub-newsletter

http://us8.campaign-archive2.com/?u=cc84aebdbf717b563d9af2ab0&id=15461503cb#Liko

Liko Nā Pilina – The Hybrid Ecosystems Project

Native Hawaiian forest species are exposed to both climate change and competition for resources with invasive species. Decimated by human activities over centuries, lowland wet forest in Hawai'i is at risk of disappearing altogether. Reducing the impact of invasive species is one step towards restoring these forests and building their resilience to climate change. A research team led by scientists from the University of Hawai'i at Hilo, the USFS Institute of Pacific Islands Forestry and Stanford University are using an innovative technique to restore degraded lowland wet forest at the Keaukaha Military Reservation in Hilo. Instead of trying to restore the forest to its historic composition by removing the invasive species and replanting with natives, these researchers are replanting both native and non- native/non-invasive species. The rationale comes from "functional trait theory" where species are selected for restoration because they have certain functional traits that can positively influence ecosystem services as a whole. One of the goals was to build invasion-resistance into the lowland wet forest by incorporating a greater diversity of functional trait expression. A second dimension to the project lies in the selection of culturally significant non-natives for replanting. In combining contemporary and traditional forest management the Liko Nā Pilina project attracted considerable public interest and is a great example of successful engagement between a local community and scientists. An early view of the research article "*Using plant functional traits to restore Hawaiian rainforest*" by Ostertag, Warman, Cordell, and Vitousek is available from [Wiley Online Library](). A [short video]() describing the work is available at the *Journal of Applied Ecology* blog.

READ MORE

UH Hilo Computer Science students

http://hilo.hawaii.edu/news/stories/2016/04/08/uh-hilo-competes-in-microsoft-us-imagine-cup/

Microsoft Imagine Cup 2016

https://www.imaginecup.com/country/details/us#in

No_Sleep - Our technology program is REST, Restoring Ecosystems Services Tool. The goal of our tool is to provide a flexible platform that can be tailored to help restore ecosystem functions using foreign non-invasive plant species, primarily focusing on ecosystems of the state of Hawaii. Currently, our program supports researchers with restoration efforts on the Big Island of Hawaii with plans to support ecosystems worldwide. Uses Windows and Visual Studio. Website

Team Member(s) Reuben Tate, Anthony Vizzone, Pauleen Pante, Bryson Fung - University of Hawaii at Hilo

Microsoft Imagine @MSFTImagine · Mar 29

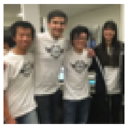
Which plants are most beneficial to revive an ecosystem? This team's program has the answer: spr.ly/6013B9Fpz

3 8

World Citizenship Category

BoloVR - B.E.S.T. Police Training Simulator is built to help de-escalate conflict to protect civilians and officers through VR training techniques. Last year, over 1200 officers and civilians were killed in our nation so our technology has honed in on the most effective inputs for virtual officer training. Uses Windows and Visual Studio. Website

Team Member(s) Eric Allen, Shahbaz Sekhon, Jed Merrill - University of Utah

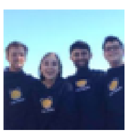


Localpulse -Imagine a smarter city - one where civic issues such as potholes, broken street signs, or graffiti can be solved more frequently and effectively by the local governments that have the power to solve those issues. We made this possible by creating Localpulse, a crowdsourced community improvement platform where people can share community issues by simply taking a picture of the problem, writing a description about it, and posting it to a readily accessible database of identified issues ranked by the votes of community members and sorted by tagged locations. Uses Microsoft Azure, Windows Phone, and Visual Studio. Website

Team Member(s) Chase Sadri, Tiancheng Gu, Ethan Lee, Elaine You Santa Margarita Catholic High School

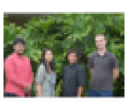
Near Field Pathology - One study has shown that greater than 9% of the lab samples are mishandled which results in losing track of critical samples. Our technology is a medical lab specimen tracking system by tagging lab samples with Near Field Communication (NFC) chips and equipping healthcare workers with NFC enabled mobile devices. Using geolocation and timestamps, this specimen tracking system is able to record the chain of custody of each step during the life cycle of a lab sample which benefits both patients and healthcare providers by reducing the current error rate and providing a more accurate process of obtaining diagnoses. Uses Microsoft Azure, Windows Phone and Visual Studio. Website

Team Member(s) Dmitry Kozlenko, Alex Mills, Kurtis Christensen, Philip Jones - Brigham Young University



RecyleBot- Our technology uses Microsoft Azure machine learning and Microsoft Kinect to identify whether an object is a recyclable so that it can put it in either recycling or garbage. This supports the larger recycling movement to protect the environment.

Team Member(s) Trent McCormick, Richard Adelstein, Matthew Blumberg, Cleo Tyler - University of California, Berkeley



No_Sleep - Our technology program is REST, Restoring Ecosystems Services Tool. The goal of our tool is to provide a flexible platform that can be tailored to help restore ecosystem functions using foreign non-invasive plant species, primarily focusing on ecosystems of the state of Hawaii. Currently, our program supports researchers with restoration efforts on the Big Island of Hawaii with plans to support ecosystems worldwide. Uses Windows and Visual Studio. Website

Team Member(s) Reuben Tate, Anthony Vizzone, Pauleen Pante, Bryson Fung - University of Hawaii at Hilo

UH Hilo Stories

'A'OHE PAU KA 'IKE I KA HĀLAU HO'OKAHI | ONE LEARNS FROM MANY SOURCES

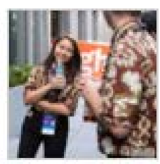
PHOTOS: Team from UH Hilo competes in Microsoft US Imagine Cup 2016 finals

Posted by Staff on April 8, 2016 | Achievements, Featured Events, Students, View All Stories

The team performed exceedingly well in their booth demo segment and in all around sportsmanship during the event.

By Susan Enright.

UH Hilo's Team No Sleep at the 2016 Microsft Imagine Cup US Finals in San Francisco. Left to right, Bryson Fung, Anthony Vizzone, Reuben Tate, and Pauleen Pante. Photos from Microsoft Imagine on flickr, Pre-Day and Competition Day. Click photos to enlarge.

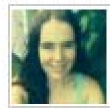
   

A team of students from the University of Hawai'i at Hilo took part in the 2016 US Imagine Cup championships last week (March 30-April 1, 2016) in San Francisco, California. Although the UH Hilo team was unable to win the national championship this year, they performed exceedingly well in their booth demo segment and in all around sportsmanship during the event.

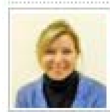
UNIVERSITY of HAWAI'I HILO

UH Hilo Stories is an online publication of the Office of the Chancellor

LATEST STORIES

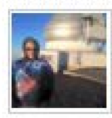

Seed exchange event hosted by UH Hilo outreach center


UH Hilo students gain insight at journalism symposium

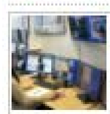

UH Hilo baccalaureate nursing program receives reaccreditation

All Stories >>

FEATURE STORIES


UH Hilo undergraduate Derek Hand conducting astronomy research on merging galaxies


UH Hilo Women's Studies program celebrates 25 years and the start of new baccalaureate degree


UH Hilo undergraduate Jasmin Silva conducting astronomy research on structure of galaxies

All Features >>

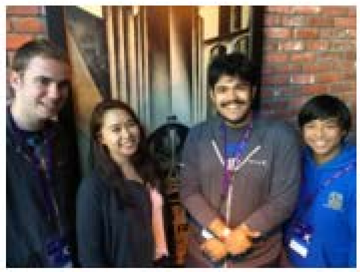
UH Hilo students **Pauleen Pante**, **Reuben Tate**, **Bryson Fung**, and **Anthony Vizzone** formed "Team No_Sleep" as part of their senior software engineering project. Their project was entitled Restoring Ecosystems Services Tool (REST), which uses principal component analysis (PCA) graphs to identify plants that are functionally similar to one another for the purposes of ecosystem restoration.

- RELATED: UH Hilo team to compete in Microsoft US Imagine Cup 2016 finals.

The project was initially undertaken for the USDA Forest Service and the UH Hilo biology department.

On March 30, Microsoft Imagine, on their Facebook page, posted a Q&A with the Hilo Team:

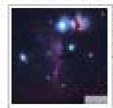
> Prior to the Imagine Cup US Finals, we spoke with Team No_Sleep from Hawaii about what they're looking forward to at the event:
>
> Q: What are you looking forward to at the Imagine Cup US Finals?
>
> A: We're looking forward to the networking opportunities at the event here in San Francisco, the learning opportunities from the guest speakers that Microsoft has lined up, and seeing what other programmers of our age are also creating as it's a good measure to see how well we are doing with our project.



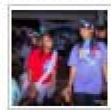
UH Hilo's Team No_Sleep takes a break during the 2016 Microsft Imagine Cup US Finals in San Francisco. (left to right) Reuben Tate, Pauleen Pante, Anthony Vizzone, and Bryson Fung. Photo from Microsoft Imagine on Facebook. Click to enlarge.

Hilo's Team No Sleep tends their booth at the 2016 Microsoft Imagine Cup competition. Photo by

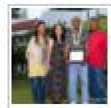
PHOTO ESSAYS



PHOTOS: UH Hilo astronomy students take spectacular pictures of night sky



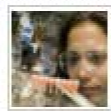
PHOTOS: 10th Annual Relay for Life, UH Hilo's only all-night event



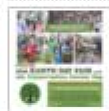
PHOTOS: Soul Food for Thought Café, final event for UH Hilo's Black History Month

More Photo Essays >>

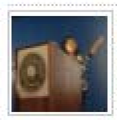
PUBLIC EVENTS & LECTURES



Monika Frazier's master thesis defense on coral health, April 13



Earth Day Fair & Conservation Career Day, April 22



UH Mānoa entomologist to give public talk on parasite affecting mac nut trees, April 11

More Events >>

Translate this Page

Select Language

Powered by Google Translate

Team advisor **Keith Edwards**, chair and professor of computer science, notes the great exposure the event gave UH Hilo on a national stage.

"UH Hilo was the only comprehensive, primarily baccalaureate granting institution to participate in the US Finals," says Keith. "The only other non R-1 participant was a top private high school with tuition exceeding UH Hilo's."

Keith Edwards

Edwards gives the Hilo competitors kudos on several fronts: The team's booth presentation and aloha shirts stood out with a Hawaiian theme, the team displayed good sportsmanship and was well-liked by the other teams, and the students networked with many contacts from around Silicon Valley including 100 recruiting and technical contacts.

Finalist teams at the US Imagine Cup Competition gather around Microsoft CEO Satya Nadella (center front in black). The UH Hilo team is at left in aloha shirts. Photo from Microsoft Imagine on Facebook. Click to enlarge.

The students came home with some great swag including Microsoft Band smart watches. They also had two days of Soft Skill Training for Students in Entrepreneurship and heard a presentation from the CEO of Microsoft Satya Nadella.

About the author of this story: Susan Enright is a public information specialist in the Office of the Chancellor. She received her bachelor of arts in English and certificate in women's studies from UH Hilo.

-UH Hilo Stories

Tagged with: Opportunities for Students

New Pre-Law Certificate approved for UH Hilo

Earth Day Fair & Conservation Career Day, April 22

Hawaii Tribune Herald, May 14, 2016

http://www.hawaiitribune-herald.com/news/community/uh-hilo-s-team-no-sleep-opens-eyes-imagine-cup

Journal of Applied Ecology:

https://jappliedecologyblog.wordpress.com/?s=ostertag

UHH Awe Lau:

Awe Lau with Nicole Martin and Taite Winthers-Barcelona.
December 7 at 8:30am ·

Liko Na Pilina Crew @Keaukaha Military Reserve surveying the hybrid hypothesis to restore lowland Hilo forests

20 Likes

Like Comment Share

Awe Lau with Nicole Martin and 24 others.
December 7 at 8:25am ·

UHH professor Becky Ostertang and team are responsible for the Liko Na Pilina or Hybrid Ecosystems Project at Keaukaha Military Reserve (KMR), Hilo.

"Liko nā pilina" loosely translates to "budding or growing new partnerships or relationships". This name was chosen because their goal is to create novel communities to restore degraded Hawaiian lowland wet forest, using non-invasive, non-native, and native species. Da combo mix plate basically.

These new novel forest are bein... See More

35 Likes 1 Share

Like Comment Share

Awe Lau with Nicole Martin and Taite Winthers-Barcelona.
December 1 at 9:00am ·

Checking out UHH Professor Becky Ostertang and research team at the Keaukaha Military Forest Reserve where they are working on their biggest project, "Liko Na Pilina"

Check out website and video:

https://sites.google.com/si…/laurawarmanecology/likonapilina… See More

9 Likes

Like Comment Share

UH-Hilo's Team No Sleep opens eyes at Imagine Cup

Published May 14, 2016 - 12:30am

Like Share 0 Tweet Pin it G+1 0 Submit

The University of Hawaii at Hilo took part in the 2016 U.S. Imagine Cup championships March 30-April 1 in San Francisco.

Computer science professor H. Keith Edwards said the team performed exceedingly well in its booth demonstration segment and in all-around sportsmanship.

UH-Hilo students Pauleen Pante, Reuben Tate, Bryson Fung and Anthony Vizzone formed Team No Sleep as part of their senior software engineering project. The project was titled "Restoring Ecosystems Services Tool," or REST, which uses PCA graphs to identify plants that are functionally similar to one another for the purposes of ecosystem restoration. The project initially was undertaken for the USDA Forest Service and the UH-Hilo Biology Department.

Some of the highlights for students included meeting contacts from throughout the Silicon Valley, admission to the Microsoft Build 2016 Conference, an Imagine Cup address by Microsoft CEO Satya Nadella and soft skill training for students in entrepreneurship.

"(Imagine Cup) gave exposure for UH-Hilo on a national stage," Edwards said. "UH-Hilo was the only comprehensive, primarily baccalaureate granting institution to participate in the U.S. finals."

Print:

Honolulu Star-Advertiser, Nov. 25, 2013

UH-Hilo effort aims to save island forests

Invasive species are being replaced with a combination of native and non-native plants

By Michael Tsai
mtsai@staradvertiser.com

Researchers from the University of Hawaii at Hilo are taking an innovative approach to forestry in an urgent attempt to save low-elevation forests in Hawaii threatened by human activity and invasive non-native flora.

Working in the Keaukaha Military Reservation in Hilo, the research team is clearing out invasive species and replacing them with a combination of native and non-native plants, creating what they have termed "hybrid ecosystems."

The non-native plants used to replace the invasive species were selected because they complement the native plants without being invasive.

The five-year, $1.5 million project, called Liko na Pilina, is being undertaken as a collaborative effort with Stanford University, the U.S. Department of Agriculture Forest Service's Institute of Pacific Islands Forestry, and the Hawaii Army National Guard.

UH-Hilo biology professor Rebecca Ostertag said the goal of the project is to create a self-sustaining forest in which native species can regenerate and thrive on

Please see FOREST, *B3*

Reyes said. "And ... supports the project, some in the community

... reporter Gordon Pang contributed to this report.

FOREST: Project is 'pretty controversial'

Continued from B1

their own.

"Our idea is that we will create better functioning forest that will be better at keeping out invasive species," Ostertag said in a news release.

Ostertag acknowledged that incorporating non-native plants in an effort to regenerate native forest is "unique and pretty controversial."

However, if successful, it could offer conservationists a means of reclaiming a battle long believed lost.

According to the researchers, lowland wet forest ecosystems have been devastated by aggressive non-native species to the point where even constant weeding may be insufficient to restore a functioning all-native ecosystem.

"Not only are we just asking some management questions; we are asking questions about fundamentally how different plant communities assemble," Ostertag said.

The project has also provided a unique learning opportunity for UH-Hilo students, interns from other universities and local high school and middle school students who help with clearing, planting and data collection.

The project is funded by the U.S. Department of Defense's Strategic Environmental Research and Development Program.

COURTESY UNIVERSITY OF HAWAII

Reforestation work in Hilo's low elevation forests uses a hybrid ecosystem strategy that involves planting both native and non-native plants.

Representatives. Duckworth deployed to Iraq in 2004 as a Black Hawk helicopter pilot with the National Guard and lost both legs and part of the use of her right arm when a rocket-propelled grenade hit her helicopter. She served as director of Illinois' Department of Veterans Affairs before President Barack Obama named her assistant secretary of veterans affairs in 2009. She continues to serve as a lieutenant colonel in the Illinois Army National Guard.

NEIGHBORHOOD BOARDS

Ala Moana/Kakaako: 7 p.m. Tuesday at Makiki Christian Church, 829 Pensacola St.

Hawaii Kai: 7 p.m. Tuesday at Hahaione Elementary School, 595 Pepeekeo St. Agenda:

>> Limited access to medical marijuana in Hawaii

>> Modernization of Koko Head Shooting Complex

Makakilo/Kapolei/Honokai Hale: Recess.

Mililani/Waipio/Melemanu: Canceled.

Neighborhood Commission: 7 p.m. today at Honolulu Hale, Room 205, 530 S. King St.

How I Learned to Love to Weed: My Month on the Big Island

I'm a New Yorker, born and raised in a city where trees are planted in five-by-three foot squares every few blocks and gardens are squeezed onto rooftops, cajoled out of postage-stamp yards, and nurtured on terraces. Green is hard to come by in New York, but growing up as the daughter of a professional gardener, I interacted with nature more than most of my peers. That's not to say that I was an expert on the subject or enjoyed the backbreaking, sweat-inducing labor involved in gardening. When I was around twelve my mom hired me to help at one of her jobs (a charming garden with a patio in Park Slope). I might have pulled up two or three weeds before she handed me a twenty (my day's salary), told me to stop whining, and sent me off to buy myself the slice of pizza that I seemed so desperately to want.

It's been four years since I was twelve (thank god) and in the meantime my appreciation of hard work and the environment has increased tenfold. Having always had an interest in journalism and a secret (though overly romanticized) yearning to save the world through environmental activism, I came to Hilo to intern for a month at *Environment Hawai'i*. I had no idea what to expect. The images I conjured up before landing in Hilo were spotty and slightly resembled a desktop screensaver: swaying palm trees, a postcard marked "Aloha From Hawai'i," scantily clad hula dancers, and waves crashing on white sand beaches. As I've come to realize since, such images reflect little of what the islands have to offer.

In my short time here I've had the good fortune to explore a range of Hawai'i's ecosystems: from the lush rainforest in Hawai'i Volcanoes National Park to the dry alpine desert on Mauna Kea. Volunteering at two forest restoration projects, one in a dry forest and another in a lowland rainforest, I was able to get up close and personal with two of the Big Island's ecosystems and help, albeit in a small way, in the effort to protect them. What's more, I wound up doing exactly what my mom had paid me not to do four years ago and found myself enjoying it.

Ava Prince weeding at Liko Na Pilina.

Pu'uwa'awa'a

Within three days of my arrival I was headed to Pu'uwa'awa'a, an area that's been chewed nearly to death by cattle, sheep, and goats for the better part of two centuries. Since 2001, stewardship of the area has been given over to the Department of Land and Natural Resources' Division of Forestry and Wildlife, which is now working to restore the land and its natural inhabitants. We — Pu'uwa'awa'a manager Elliott Parsons, *Environment Hawai'i* editor Pat Tummons, two students and myself — were the first group to outplant threatened and endangered trees in Waihou, a 204-acre fenced conservation unit high in the ahupua'a. Armed with planting tools, watering buckets, and healthy aiea, halapepe, and kauila seedlings, we bounded over weeds and weathered lava in one of the roughest truck rides I've ever been on. I clutched my seat as the pickup bounced mercilessly onward, keeping my eyes focused on what was outside the window. I'm not exactly an expert, but even so, what I saw didn't seem to represent "…the richest floral section in the whole territory," which is how famed botanist Joseph Rock described the area he saw in a visit in 1913. The landscape that was once dense with "luxurious vegetation" is now mostly covered in a carpet of invasive kikuyu grass, with the occasional 'ohi'a or mamane tree peeking out tentatively alongside the scraggly remains of their predecessors. Along the way, a few herds of wild goats or sheep would quickly leap across our path, and at one point we were chasing a directionally likeminded turkey as he scuttled down the road ahead of us. Parsons would stop the truck at times to point out recent accomplishments — school-kid projects and successes in other management units — before navigating us, safe yet shaken, to Waihou.

Well before our arrival, other work crews had cleared plots in our worksite using pesticides. The grey circles of the dead kikuyu polka-dotted the landscape, with colorful flags popping up to show where previous groups had planted koa and other natives. Our small crew added just 24 more trees and spent the rest of the day weeding. This foe from long ago was soon to become a friend, however, as I pulled at these weeds with a ferocity and the same feeling of triumph Superman must feel as he lifts cars and rescues small children.

"The personal fulfillment one gets out of doing projects here is enormous," Parsons wrote in an email to me, and I can understand.

Uprooting weeds and digging through the 'a'a lava, you can easily become consumed with the small details: the ache in your lower back, the blisters on your hands, the stone you want to wrench out of the ground that turns out to be a boulder. It's easy to forget how much larger the project is and how much work you have left to do.

Liko Na Pilina

"There were various times when I definitely felt overwhelmed. But then we hired an amazing team of people, and having them on board, and all the teamwork involved gave me a lot of confidence that we could do this," says Rebecca Ostertag, one of the main researchers at Liko Na Pilina (otherwise known as the Hybrid Ecosystems Project). This project is located alongside the Hilo airport at the Kilauea Military Reservation (KMR), where Ostertag and her team are experimenting using a blend of native and introduced, non-invasive trees to restore the lowland wet forest.

As at Pu'uwa'awa, Ostertag's team needed to set up and clear plots to carry out their research. Unlike Pu'uwa'awa'a, however, where the largest weed I encountered was a two-foot-high thistle, the crews at Liko na Pilina faced 30-foot-tall trees that had intertwined with one another over time. All the trees that were not native or part of the hybrid collection were cut down. Think of it as extreme weeding. As I viewed the control areas, I couldn't imagine trying to cross them on foot, let alone march through them with a chainsaw. I feared I would trip when I'd walked just a few feet out of the plot to use the facilities supplied by the overgrowth. Covered completely by the rows and rows of tangled forest, the alterations Ostertag and her team are making in the plots are invisible unless one, for some inexplicable reason, were to leave the road and plow through the dense weeds for a good five minutes.

I spent my days at Liko Na Pilina weeding, yet again. While doing so I found myself enjoying not only what had become my new favorite hobby but also the communal atmosphere brought by the members of the team. The physical wear and tear of the day's work was balanced by cheerful gossip, the easy banter and conversation making the day seem

Hawaii Report

Long-term care program lauded

HONOLULU (AP) — Hawaii's long-term care program has been lauded by a national group as one of five pioneering and innovative state Medicaid programs.

The Center for Health Care Strategies calls Hawaii's QUEST Expanded Access program a "true pioneer" in designing innovative approaches to delivering care to about 40,000 low-income seniors and disabled persons.

According to state officials, Hawaii was specifically recognized for its transparency and intensive communication with key lawmakers, interested groups and the public at least two months before the

'Hybrid ecosystem' to be studied

By AUDREY McAVOY
Associated Press

HONOLULU — Invasive species are so pervasive in Hawaii's low-lying areas that the U.S. Forest Service says it's not cost-effective or practical to eradicate them all. Instead, it's launching new research into developing "hybrid ecosystems" that will incorporate some nonnative plants but allow native plants to thrive.

The service has received a $1.6 million grant from the Defense Department's strategic environmental research program to study the possibility.

"Invasive species are so prevalent. You're hand weeding, trying to eliminate them and aren't able to keep up with them. It feels like you're fighting a losing battle," said Susan Cordell, research ecologist with the Forest Service. "Restoring these lowland tropical forests to a historic native state is not financially or physically feasible."

Hawaii's low-lying native trees and plants were wiped out by cattle, goats and other nonnative mammals that were set free to graze after the arrival of the first Europeans in the islands in the late 1700s.

The animals trampled on ferns and undergrowth, drying the soil and tree roots. Later reforestation efforts resulted in the planting of fast-growing nonnative trees like eucalyptus instead of native trees.

To see intact native ecosystems, you have to climb high into the mountains.

Cordell said the grant will allow researchers to find ways for native species to "coexist" wit some nonnative species.

The study, to be carried out at Keaukaha Military Reservation, a 200-acre site on the Big Island run by the Army National Guard, is due to begin in April and last for five years.

The first phase is a 14-month analysis of existing native and nonnative species. The second phase will involve test plantings of several species combinations.

Rebecca Ostertag, a University of Hawaii at Hilo biology associate professor, and Peter Vitousek, a biology professor at Stanford University, are due to be part of the research team along with Cordell.

Sam Gon, a senior scientist and cultural adviser with the Nature Conservancy of Hawaii, said the idea of hybrid ecosystems is not entirely new, and reflects some realism.

While Gon would like to see ecosystem efforts assert native species as much as possible and see native plants re-established in areas where they're not longer found, he also recognizes this is difficult and time consuming.

"Sometimes you find that they actually hold their own pretty well as long as you don't have things like fire or other major disturbances," Gon said. "And other times you find the moment you stop caring for them and actively removing their competitors, within the course of five years or so, you barely know that the place had native plants at all."

Gon said hybrid ecosystems could be part of a spectrum that would also include purely native ecosystems.

"It's just maybe the realization that even though we would like to see nothing but natives, we might have to settle for being happy to see a percentage of natives," Gon said.

He said this would still be an improvement compared with the 1950s or even 1970s in Hawaii, when there weren't any native plants in the lowland parts of the islands.

> "Invasive species are so prevalent. ... It feels like you're fighting a losing battle. Restoring these lowland tropical forests to a historic native state is not financially or physically feasible
>
> — *Susan Cordell, research ecologist with the Forest Service*

Appendix 3. Publications and presentations to date.

Publications

Schulten, J., C. Cole, S. Cordell, K. Publico, R. Ostertag, J. Enoka, and J.M. Michaud. 2014. Persistence of native trees in an invaded Hawaiian lowland wet forest: Experimental evaluation of light and water constraints. Pacific Science: 2: 267-285.

Cavaleri, M.A., Ostertag, R. Cordell, S. and Sack, L. 2014. Hawaiian Conservation Physiology: Native trees show conservative water use relative to invasive: results from a removal experiment in a Hawaiian wet forest. Conservation Physiology 2: doi:10.1093/conphys/cou016.

Uowolo, A. 2014. Liko Nā Pilina: Developing hybrid ecosystems that enhance carbon storage, native biodiversity, & human mobility in lowland Hawaiian Forests. Unpublished Brochure.

Michaud, J., S. Cordell, T.C. Cole, and R. Ostertag. 2015. Drought stress in an invaded Hawaiian lowland wet forest. Pacific Science 69: 367-383.

Ostertag, R., L. Warman, S. Cordell, and P.M. Vitousek. 2015. Using plant functional traits to restore Hawaiian rainforest. Journal of Applied Ecology 52: 805-809.

McAuliffe, S. J.I. Martes Martinez, L. Warman, and R. Ostertag. 2015 (November). Herbivory and Arthropod Diversity within Invaded and Native Forest Types on Hawai'i Island. Journal of Young Investigators 29 (5), online: http://www.jyi.org/issue/herbivory/.

Rosam, J.R. 2015. Assessment of light quality, variability, and seedling presence in Hawaiian lowland wet forests. University of Hawaiʻi at Hilo, Hilo, HI.

Cordell, S., R. Ostertag, J. Michaud, and L. Warman. 2016. Quandaries of a decade long restoration experiment trying to reduce invasive species: Beat them, join them, give up, or start over? Restoration Ecology 24: 139-144.

Ostertag R., D. Rayome, S. Cordell, P. Vitousek, B. Fung, P. Pante, R. Tate, and A. Vizzone. 2016. Restoring Ecosystem Services Tool (REST) User Guide, V 1.3. Prepared for SERDP project RC-2117 by the University of Hawaii at Hilo, USDA Forest Service, and Stanford University.

In preparation:

Jennison, C., D. Rayome, R. Ostertag, and S. Cordell, and Y. Mahli. Can we restore native Hawaiian forests while optimizing food production and carbon sequestration? An analysis of yields. In preparation for Journal of Sustainable Forestry.

Jennison, C., D. Rayome, R. Ostertag, and S. Cordell, and Y. Mahli. Can we restore native Hawaiian forests while optimizing food production and carbon sequestration? An analysis of carbon storage. In preparation for New Forests.

Rayome, D.D., R. Ostertag, and S. Cordell. Economic analysis of key ecosystem services in a hybrid wet forest restoration experiment. Submitted Aug 2016 to Ecological Economics.

Rayome, D.D., R. Ostertag, and S. Cordell. Estimates of carbon worth in a hybrid wet forest restoration experiment. In preparation for Unasylva.

Rayome, D.D., R. Ostertag, and S. Cordell. Exergy analysis of a hybrid wet forest restoration experiment. In preparation for Ecological Engineering.

Rosam, J.R., L. Warman, R. Perroy, R. Ostertag, and S. Cordell. Assessment of light quality, variability, and seedling presence in Hawaiian lowland wet forests. In preparation for Journal of Applied Ecology.

Warman, L., R. Ostertag, S. Cordell, P. Vitousek, M. Stewart, J. Schulten, and A. Uowolo. Plant traits in Hawaiian lowland wet forests. In preparation for Plant Ecology.

Warman, L., R. Ostertag, S. Cordell, N. Zimmerman, and J. Mascaro. From species ID to community FD: Measures of functional diversity along a ‘novelty gradient’ in Hawaiian lowland wet forests. In revision for Journal of Ecology.

Presentations/Posters

Ostertag, R., S. Cordell, and P. Vitousek. 2011, 2012, and 2013, 2016. Hybrid ecosystems. Hawai’i Ecosystems Meeting, Hilo, HI.

Chu, C. 2011. Evaluating specific leaf area as a functional trait in the assembly of new Hawaiian forest communities, Stanford University Symposia of Undergraduate Research and Public Service (SURPS and ASURPS).

Ostertag, R., S. Cordell, P Vitousek, L. Warman, J. Schulten, A. Uowolo, P.K. McGuire-Turcotte. 2011. Developing novel ecosystems that enhance carbon storage, native biodiversity, and human mobility in lowland Hawaiian forests, SERDP Partners in Environmental Technology Technical Symposium and Workshop, Washington, DC.

Cordell, S. 2012. The fate of Ohia forests; evidence from seed dynamics, invaded systems, and successional pathways. Hawai‘i Conservation Conference, July 31-Aug.2. Honolulu, HI. (Invited oral presentation).

Schulten, J. 2012. Shining light on native species: can hybrid ecosystems become resistant to invasions? Hawai‘i Ecosystems Meeting, July 2012, Hilo, HI.

Warman, L. 2012. University of Hawai‘i at Hilo’s Tropical Conservation Biology and Environmental Science Symposium on April 12, 2012.

Warman, L., S. Cordell, R. Ostertag, J. Schulten, A. Uowolo, and P. Vitousek. 2012. Fantasy football for community ecologists: building hybrid ecosystems in Hawaiian lowland wet forests. Ecological Society of America Annual Conference, August 5-10. Portland OR.

Cavaleri, M.A., L. Sack, S. Cordell, R. Ostertag, J. Michaud. 2013. Water use of native and invasive trees in a lowland tropical rainforest in Hawaii. Ecological Society of America, August 4-9, 2013, Minneapolis, MN.

MacAuliffe, S., J.I. Martes-Martinez, L. Warman, and R. Ostertag. 2013. Liko Nā Pilina: Arthropod communities and herbivory in Hawaiian lowland wet forest. Conference on Undergraduate Research; October 27-28, 2013, Arlington, VA.

Stewart, M., L. Warman, and R. Ostertag. 2013. Let's keep the fun in functional diversity: A comparison of seedling functional traits in a lowland wet forest in eastern Hawai'i Island. Student Research Symposium, CTAHR, UH Manoa (Gamma Sigma Delta Undergraduate oral presentation).

Stewart, M., L. Warman, and R. Ostertag. 2013. Let's keep the fun in functional diversity: A comparison of seedling functional traits in a lowland wet forest in eastern Hawai'i Island. Tester Symposium, UH Manoa (best undergraduate oral presentation).

Chikasuye, K. 2014. Preliminary seed and litter data from the Liko na Pilina restoration experiment, TCBES Symposium, April 3, 2014, Hilo, HI.

Cordell, S. 2013. Pro-bowl for restoration ecologists: Using a plant functional trait approach to pick a winning team. Hawaii Volcanoes National Park After Dark in the Park Lecture Series, November 5, 2013.

Ostertag, R., L. Warman, S. Cordell, and P. Vitousek. 2013. A functional trait approach to nutrient cycling and restoration. Association for Tropical Biology and Conservation, June 24-27, 2013, San José, Costa Rica.

Schulten, J. 2013. Shining Light on native Species: An assessment of the understory light environment in Hawaiian lowland wet forests, TCBES Symposium, May 13-15, 2013, Hilo, HI.

Warman, L., S. Cordell, R. Ostertag, J. Schulten, A. Uowolo, and P. Vitousek. 2013. Fantasy football: A trait-based approach for species choice in restoration. Hawai'i Conservation Conference, July 16-18, 2013. Honolulu, HI.

Warman, L., R. Ostertag, and S. Cordell. 2013. Measures of functional diversity across an invasion gradient in Hawaiian lowland wet forests. Association for Tropical Biology and Conservation – June 24-27, 2013, San José, Costa Rica.

Cordell, S., R. Ostertag, L. Warman, P. Vitousek, J. Schulten, A. Uowolo and N. DiManno. 2014. Restoring ecosystem function using hybrid ecosystems. Association for Tropical Biology and Conservation, June 24-27, 2014, Cairns, Australia.

Cordell, S. 2014. Pro-bowl for restoration ecologists: Using a plant functional trait approach to pick a winning team. USDA Forest Service Washington Office.

DiManno, N. 2014. Seedling recruitment: Promising steps towards restoring Hawaiʻi's degraded lowland wet forest. Hawaiʻi Ecosystems Meeting. June 25-26, 2014 Hilo, HI.

Schulten, J. 2014. A sneak peek into Hawaii's red-light district. Hawaiʻi Ecosystems Meeting. June 25-26, 2004 Hilo, HI.

Warman, L., R. Ostertag, S. Cordell, J. Mascaro, and N. Zimmerman. 2014. Functional diversity across a "native to novel" gradient in Hawaiian rainforests. Association for Tropical Biology and Conservation, July 20-24, 2014, Cairns, Australia.

Warman, L. 2014. Community level functional diversity across an invasion gradient in Hawaiian lowland wet forests, TCBES Symposium, April 3-4, 2014, Hilo, HI.

Ostertag, R., L. Warman, S. Cordell, P. Vitousek, N. DiManno, A. Uowolo, T. Winthers-Barcelona, and J. Schulten. 2015. Testing functional trait theory and invasion resistance in Hawaiian lowland wet forest restoration. Association for Association for Tropical Biology and Conservation, July 12-16, 2015, Honolulu, HI.

Ostertag, R., S. Cordell, P. Vitousek, L. Warman, J. Schulten Rosam, A. Uowolo, N. DiManno, T. Winthers-Barcelona, J. Norton, and T. Antunes Maia. 2015. Liko Nā Pilina: The hybrid ecosystems project. Hawaiʻi Conservation Conference, August 3-6, Hilo, HI.

Ostertag, R., L. Warman, S. Cordell, P. Vitousek, N. DiManno Martin, T. Winthers-Barcelona, T., J. Rosam, and A. Uowolo. 2015. Can restoration using a functional trait based approach provide invasion resistance? An example in novel ecosystems of Hawaii, EMAPI, Sept. 20-24, Waikoloa, HI.

Rosam, J., R. Ostertag, S. Cordell, L. Warman, and J.P. Price. 2015. Patterns of light quantity, quality, and seedling presence in Hawaiian lowland wet forests across an invasion gradient. Association for Association for Tropical Biology and Conservation, July 12-16, 2015, Honolulu, HI.

Rosam, J., R. Ostertag, J.P. Price, S. Cordell, and L. Warman. 2015. Assessment of understory light in Hawaiian lowland wet forests across a species-dominance gradient. Hawaiʻi Conservation Conference, August 3-6, Hilo, HI.

Ostertag, R., Cordell, S., Vitousek, P., Rayome, D.D., Uowolo, A., Martin, N., Fung, B., Pante, P., Tate, R., Vizzone, A., 2016. Workshop on functional trait-based restoration. Mar 3, 2016. Hilo, HI.

Ostertag, R., Cordell, S., Vitousek, P., Rayome, D.D., Uowolo, A., Martin, N., Fung, B., Pante, P., Tate, R., Vizzone, A., 2016. Workshop on functional trait-based restoration. April 5, 2016. Honolulu, HI.

Rayome, D.D. 2016. BioValue: A new technique for valuing biodiversity in novel Hawaiian ecosystems. TCBES Research Symposium, April 8, 2016, Hilo, HI.

Ostertag, R., N. DiManno Martin, L. Warman, S. Cordell, A. Uowolo, J.Schulten Rosam, Taite Winthers-Barcelona, and Peter Vitousek. 2016. Evaluating novel species mixtures in a functional trait-based restoration experiment. Association for Association for Tropical Biology and Conservation, June 19-23, 2016, Montpellier, France.

Rayome, D.D. 2016. Economic analysis of ecosystem services in a hybrid wet forest restoration experiment. Hawai‘i Ecosystems Meeting. July 7-8, 2016 Hilo, HI.